Mistaken Point

Nomination for Inscription
UNESCO World Heritage List

WHEN LIFE GOT BIG

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Newfoundland and Labrador,
Canada

Executive Summary

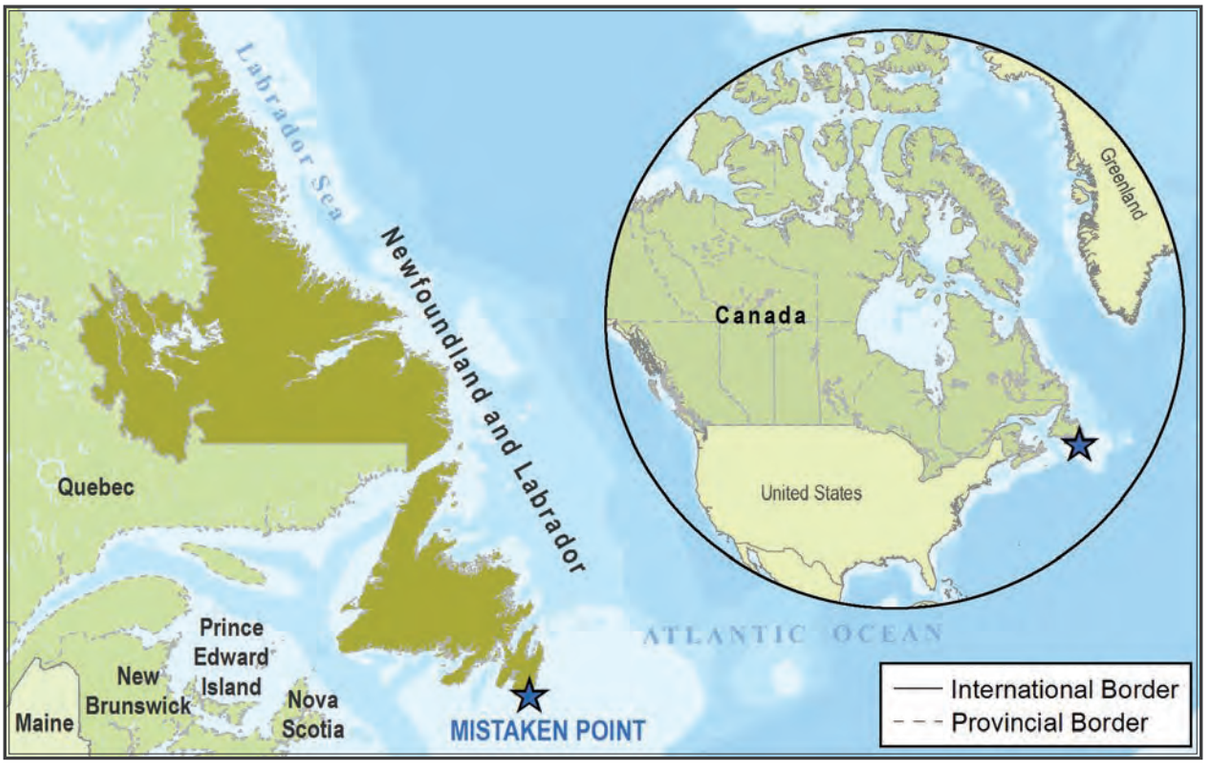
State Party:	Canada
Province:	Newfoundland and Labrador
Name of Property:	Mistaken Point
Geographical Co-ordinates:	46° 38' 6" North 53° 12' 40" West

Textual Description of the Boundary of the Nominated Property

The nominated property is located in the province of Newfoundland and Labrador, Canada, on the island of Newfoundland's Avalon Peninsula. Situated between the town of Portugal Cove South and Cape Race, the nominated property extends along 17 kilometres of coastline from Daleys Point to Shingle Head. Most of the nominated property lies inside the boundaries of Mistaken Point Ecological Reserve, a provincial protected area. A very small portion (0.03 percent) lies within an adjoining provincial Crown Lands Reserve.

The nominated property begins at the ordinary low water mark and extends inland to an easily identifiable natural feature, the turf edge. The turf edge is the seaward-most extension of contiguous clifftop vegetation.

The buffer zone is a strip of land generally 30 metres wide that extends inland from the landward boundary of the nominated property. The buffer zone's shape and size are designed to absorb the effects of anticipated natural coastal erosion for at least several hundred years. The buffer zone's inland boundary is fixed. Therefore, as erosion causes the nominated property boundary to recede inland, the width of the buffer zone will very gradually decrease over time.



Regional setting of the nominated property.

The nominated property and buffer zone.

Criteria Under Which Mistaken Point is Nominated for Inscription

Mistaken Point is herein nominated for inscription to the World Heritage List under criterion (viii) of Paragraph 77 of the *Operational Guidelines for the Implementation of the World Heritage Convention* (2013), which states that such properties shall:

> **Be outstanding examples representing major stages of earth's history, including the record of life,** significant ongoing geological processes in the development of landforms, or significant geomorphic or physiographic features.

Mistaken Point is nominated as the site that best illustrates the earliest stages in the emergence of biological complexity on our planet, "when life got big," 580 million years ago during the Ediacaran Period. The many thousands of impressions of soft-bodied, centimetre- to metre-scale creatures preserved at Mistaken Point document the oldest large and biologically complex creatures known anywhere and are generally regarded as including the earliest (stem-group) ancestors of the animals. The nominated property of Mistaken Point also provides key information about the ecology of these ancestral animals and about the early colonization of the deep-sea floor.

Draft Statement of Outstanding Universal Value

Brief Synthesis

Mistaken Point is a globally significant Ediacaran fossil site almost entirely located within Mistaken Point Ecological Reserve on the southeastern tip of the island of Newfoundland in eastern Canada. The 146-hectare property consists of a narrow, 17-kilometre-long strip of rugged and scenic coastal cliffs, with an additional 74 hectares adjoining its landward margin designated as a buffer zone. The superbly exposed, 2-kilometre-thick rock sequence of deep marine origin at Mistaken Point dates to the middle Ediacaran Period (580 to 560 million years ago) and contains exquisitely preserved assemblages of the oldest abundant and diverse, large fossils known anywhere.

More than 10,000 fossil impressions, ranging from a few centimetres to nearly 2 metres in length, are readily visible for scientific study and supervised viewing along the coastline of Mistaken Point. These fossils illustrate a critical watershed in the history of life: the appearance of large, biologically complex organisms, including the first ancestral animals. Most of the fossils are rangeomorphs, an extinct group of fractal organisms positioned near the base of animal evolution. These soft-bodied creatures lived on the deep-sea floor, and were buried and preserved in exceptional detail by influxes of volcanic ash—each layer of ash creating an "Ediacaran Pompeii." Modern erosion has exhumed more than 100 fossil sea-floor surfaces, ranging from small beds with single fossils to tennis-court-sized surfaces adorned with up to 4,500 megafossils. The animals died where they lived, and their resultant fossil assemblages preserve both the morphology of extinct groups of ancestral animals and the ecological structure of their ancient communities. Radiometric dating of the volcanic ash beds that directly overlie the fossil-bearing surfaces is providing a detailed chronology for 20 million years in the early evolution of complex life.

Justification for Criteria

Criterion (viii): Mistaken Point fossils constitute an outstanding record of a critical milestone in the history of life on Earth, "when life got big" after almost three billion years of microbe-dominated evolution. The fossils range in age from 580 to 560 million years, the longest continuous record of Ediacara-type megafossils anywhere, and predate the Cambrian explosion (the oldest fossil evidence of ancestors of most modern animal groups) by more than 40 million years. Mistaken Point contains the world's oldest-known examples of large (up to 2 metres long), architecturally complex organisms, including soft-bodied, ancestral animals. Ecologically, Mistaken Point contains the oldest and most diverse examples of Ediacaran deep-sea communities in the world and the earliest documented examples of ecological tiering and secondary community succession. Other attributes contributing to the property's Outstanding Universal Value include the world's first examples of metazoan locomotion, exceptional potential for radiometric dating of the assemblages, and evidence for the role of ancient oxygen levels in the regional and global appearance of complex multicellular life.

Integrity

The clearly defined property boundary encompasses coastal exposures preserving all the features that convey its Outstanding Universal Value. All of the key fossils and strata are within the property. The width of the property and its buffer zone are sufficient to absorb the very gradual, long-term retreat of the coastline due to natural erosion.

The vast majority of Mistaken Point's fossils—including several type specimens—remain in situ in the field and are available for ecological study in their original context. The property is thought to contain more specimens of Ediacara-type impression fossils than the sum total of every museum collection on Earth. Several hundred specimens were collected prior to Mistaken Point Ecological Reserve being established; most of these are currently housed in the Royal Ontario Museum and form the bulk of the type specimens for taxa named and defined from Mistaken Point.

Few traces of past human activities remain and none directly affect the property's key attributes. The prospect of modern development within or adjacent to the property is minimal and does not impinge upon its coastal outcrops. Incidents of vandalism are very rare and no successful fossil thefts have occurred since the property was designated as an ecological reserve in 1987. No inhabitants reside permanently within the property or its buffer zone.

Protection and Management Requirements

The property is provincially owned and is managed by the Parks and Natural Areas Division of the Newfoundland and Labrador Department of Environment and Conservation. Virtually all of the property, plus most of its buffer zone, lie within Mistaken Point Ecological Reserve which is protected under the Province's *Wilderness and Ecological Reserves Act* (1980) and *Fossil Ecological Reserve Regulations* (2009). With one exception, the remaining portions of the property and buffer zone are protected as Crown Lands Reserves under the provincial *Lands Act* (1991). Only one small part (0.5 percent) of the buffer zone has been identified as private land; current and anticipated land use is complementary to the rest of the buffer zone.

The property's key coastal exposures are further protected by the ecological reserve's Fossil Protection Zone; access to this zone is by permit only. Undertaking activities such as scientific research at Mistaken Point requires a permit issued by the managing agency. Development is prohibited within the ecological reserve.

The comprehensive management plan developed for the property and its buffer zone is adaptive and will be revised as required. Input from local residents regarding management issues is channelled through the property's World Heritage Advisory Council. For management purposes, the property is best treated as a finite fossil site. Except for official salvage of scientifically valuable specimens, collecting fossils is illegal. For conservation reasons, public viewing of the fossils is by guided tour only. Daily patrols of the property are conducted year-round and a volunteer Fossil Guardian Program is in operation.

The most significant threats to the integrity of the property stem from natural erosion processes and human activity. Under the monitoring plan, vulnerable fossil localities are regularly surveyed and any problems documented. Where practicable, mitigation measures are undertaken. The carrying capacity of the property is limited and the cumulative environmental impact of visitation is closely monitored. Emplacement of limited infrastructure to aid presentation of the property is carefully designed to avoid adverse impacts upon the property's Outstanding Universal Value.

Through its long-term commitment to provide operational funding and staffing, the Government of Newfoundland and Labrador will ensure that the highest possible standards of protection and presentation are maintained in the property.

Figure 1.1. Regional setting of the nominated property.

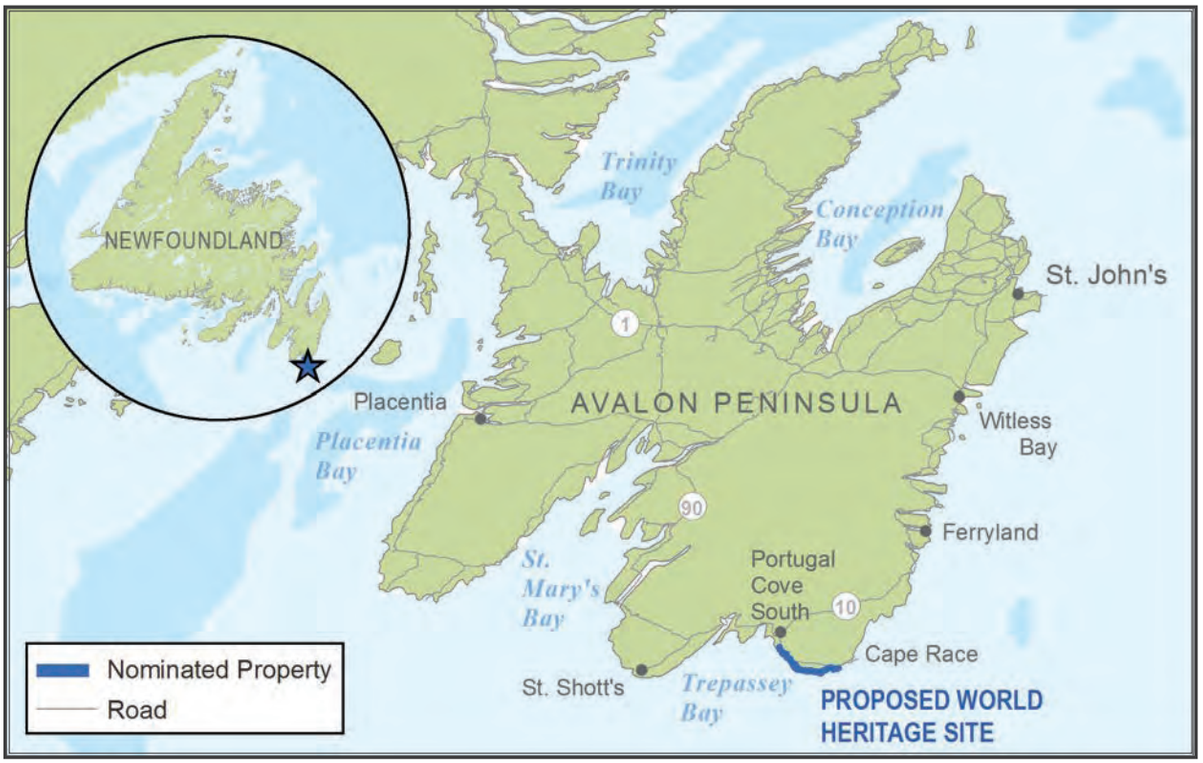


Figure 1.2. The nominated property is located on the Island of Newfoundland's Avalon Peninsula.

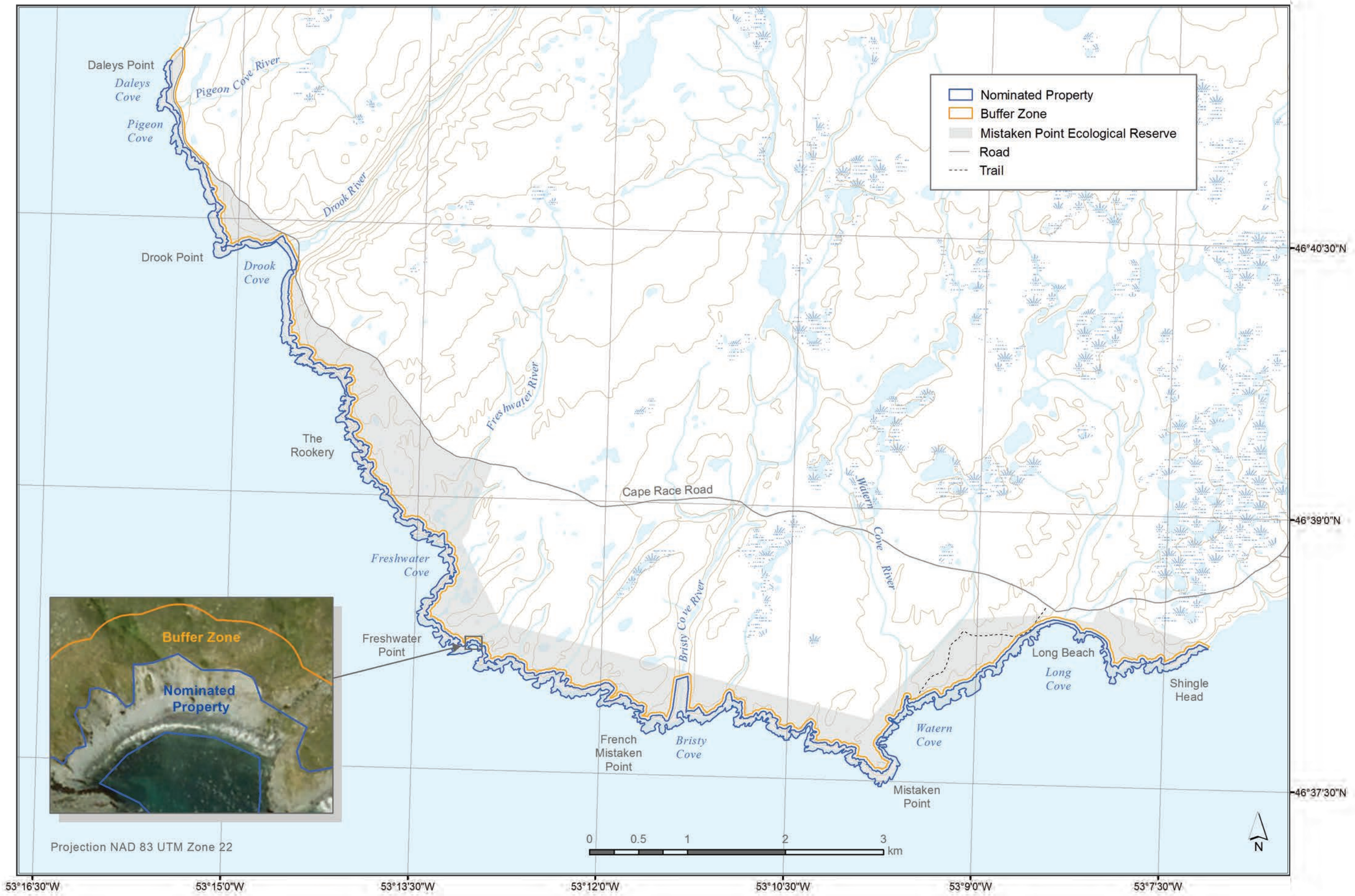


Figure 1.3. The nominated property and buffer zone.

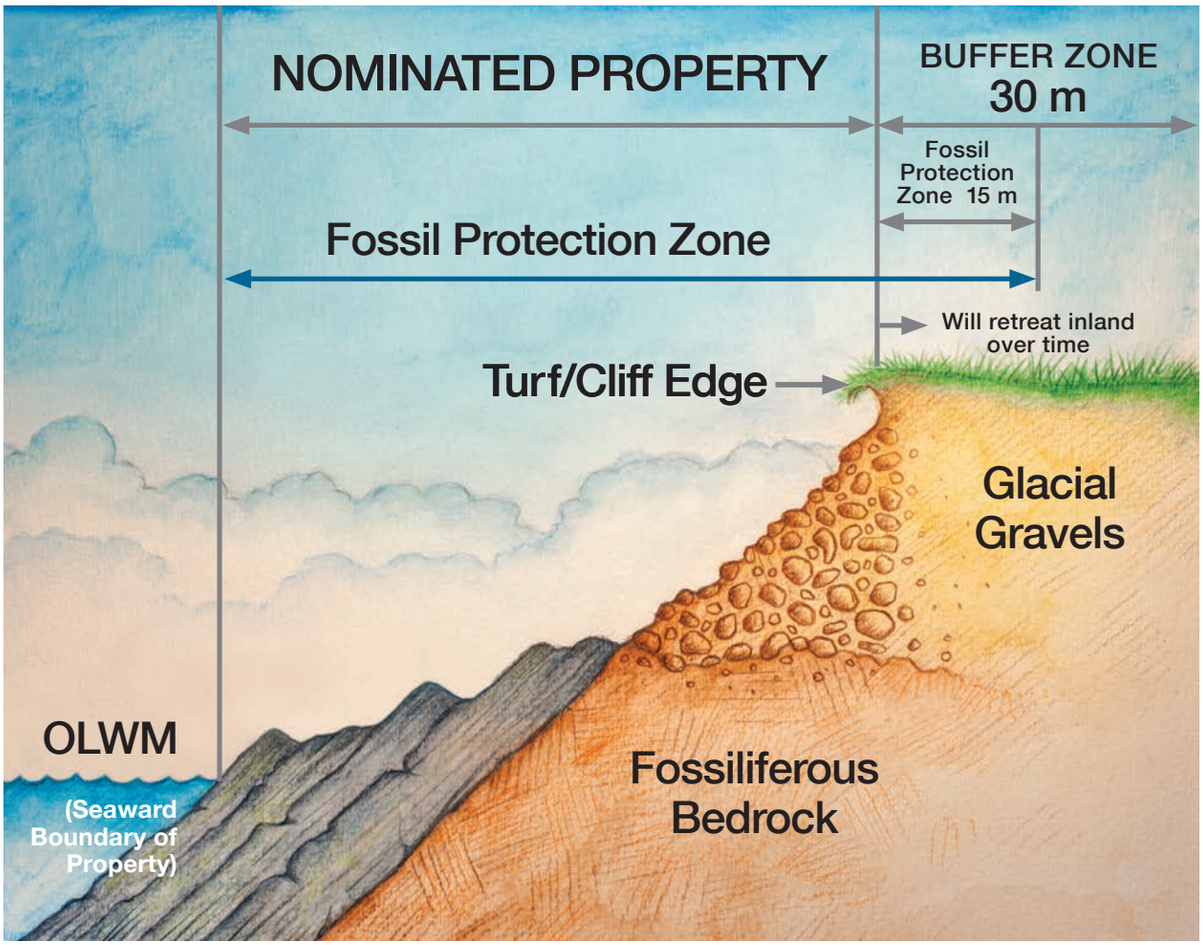


Figure 1.4. Schematic cross-section showing the boundaries of the nominated property and its buffer zone, and Mistaken Point Ecological Reserve's Fossil Protection Zone; OLWM = ordinary low water mark.

Figure 1.5. The landward boundary of the nominated property near Daleys Cove, showing the contiguous turf edge (black arrow) and a detached "raft" of vegetation (red arrow) that has slid downslope.

Figure 1.6. The seven locations where the inland boundary of the nominated property does not follow the turf edge.

Figure 1.7. The majority of the buffer zone extends 30 metres inland from the landward boundary of the property; the buffer zone is wider in one location due to higher rates of erosion (inset).

Section 2:

Description

Figure 2.1. The Mistaken Point promontory in the distance, looking southwest from Watern Cove.

2.a Description of Property

2.a (i) Introduction

Newfoundland—the island portion of Canada's most easterly province, Newfoundland and Labrador—is situated in the North Atlantic Ocean, where the Gulf Stream and the Labrador Current come together. Its most easterly area is the Avalon Peninsula (Figures 1.1 and 1.2), and the nominated property is located near this peninsula's southeasternmost corner, where the coast forms a roughly south-facing arc between the headland of Cape Race and the community of Portugal Cove South. It is a rugged, windswept area with geological links to an ancient landmass once positioned near northern South America, and with abundant evidence of deep-ocean life forms that flourished more than half a billion years ago.

The nominated property comprises a low, narrow, 17-kilometre-long coastal strip extending from Daleys Point (1 kilometre south of the Town of Portugal Cove South) in the northwest, to just east of Shingle Head (approximately 4.5 kilometres southwest of Cape Race), in the southeast (Figure 1.3). Mistaken Point itself (Figure 2.1), the southeast-directed promontory for which the entire nominated property is named, is the most obvious topographic feature within its boundaries.

Why Is It Called "Mistaken Point"?

The name "Mistaken Point" is related to Newfoundland's nautical heritage. Before modern electronic navigation aids simplified fixing a ship's position in fog or darkness, Mistaken Point was often confused with nearby Cape Race, the Avalon Peninsula's actual southeast "corner"—an error with potentially fatal consequences. From 1864 to 1904, 94 ships were wrecked near Cape Race with the loss of about 2,000 lives.

Figure 2.2. Main outcrop of the famous D (greenish hue) and E (reddish hue) fossil-bearing surfaces (centre right) of the Mistaken Point Formation. Dip is to the east at 14°. Overlying the bedrock is a sheet of unconsolidated, Quaternary gravel.

Geologically this coast is composed of Precambrian bedrock unconformably overlain by a late Pleistocene, 0- to 4-metre-thick sheet of unconsolidated, very poorly sorted, granule- to boulder-grade gravel (diamicton) of glacial origin (Figure 2.2). Ninety percent of the nominated property's shoreline comprises bedrock exposures, while the remainder is occupied by nine cobble-grade gravel beaches, the longest stretch of which (uninterrupted by rock outcrops) is about 375 metres in length. Elevations at the turf/cliff edge vary from 1 to 76 metres above sea level (Figure 2.3), while the width of the outcrops between the cliff/turf edge and the low water mark ranges

Figure 2.3. Seventy-five-metre-high cliffs at The Rookery. These Drook Formation rocks are the oldest in the nominated property.

Figure 2.4. Bedding plane slots formed by weathering of less resistant volcanic ash layers. Drook Formation, south of Pigeon Cove.

from 0 metres (vertical cliffs) to about 100 metres. Apart from a variety of rock platforms and cliff types, other geomorphological features present along the coast are small coves and gullies, larger steep-sided gulches, small and large headlands, pocket beaches, narrow sub-vertical slots eroded along faults and master joints, reefs, islets, sea stacks, sea caves, and small rock arches (Figure 2.3). For a more detailed description of the most notable geographic and geological features of the nominated property's coastline, see Appendix 6.

The five formations found within the nominated property (see Section 2.a (ii)) consist largely of mudstones and fine-grained sandstones, and vary only in the relative proportions of their constituent lithologies and the average bedding thickness of their lithological units. As a result, while they do show some distinctive weathering characteristics, there are no consistent differences among the geomorphological expressions of these formations' coastal outcrops.

The main influence in shaping the character of the Mistaken Point coast under its present erosion regime, other than the effects of the last glaciation and its bedrock lithologies, is its geologic structural elements. These include the types and orientations of folds and faults, bedding planes, cleavage, and fractures. Most rock types at Mistaken Point are well indurated and relatively resistant to erosion. The volcanic ashes and ash-rich mudstones, however, are less indurated and erode more readily—forming recessive, bedding-parallel slots (Figure 2.4). These latter rock types typically weather white, light green, or grey-green. Most of the rocks in the nominated property are siliceous in composition and brittle in nature. They are cut by numerous conjugate joint sets and other fracture systems (Figure 2.5) that, in combination with bedding type and thickness, cleavage, and lithological composition, dictate how the strata weather and erode.

The tidal regime at Mistaken Point is semi-diurnal and microtidal[1], with a maximum normal tidal range of 1.9 metres measured in nearby Trepassey Harbour. Within the nominated property, intertidal zone width is in the order of tens of metres or less. Average wave energy along this stretch of northwest Atlantic coastline is high.

2.a (ii) The Geological Record

The coastal section comprising the nominated property superbly exposes a 2-kilometre-thick, highly fossiliferous succession of middle-Ediacaran (approximately 580-

Figure 2.5. Bedding plane near tip of Mistaken Point, cut by conjugate joint sets, multiple other fractures and a pervasive spaced cleavage (sub-parallel to direction of view).

to 560-million-year-old) sandstones and mudstones (Figure 2.6). Impressions of Ediacara-type megafossils occur throughout the succession, making it the thickest to contain such fossils in the world. The stratigraphic sequence within the nominated property consists of the upper half of the Conception Group and the lower half of the overlying St. John's Group, and these groups are further subdivided into five formations (Figure 2.7). All of the contacts between formations are concordant and gradational, with no physical evidence of erosion, supporting the view that the Mistaken Point succession represents relatively continuous deposition. Most of these strata are turbidites.[2-7]

Stratigraphy of the Conception Group

The Conception Group is characterized by thin to thick beds of sandstone turbidite separated by silicified beds of mudstone. There is no evidence of exposure surfaces, wave ripples, or any other shallow-water features. Volcanic ash is abundant and occurs as layers of crystal tuff, ash-rich turbidites, and fine-grained volcanic material disseminated throughout the sandstone beds. Compositionally, the volcanic ash is silica-rich dacite,[8] whose subsequent alteration has led to the abundant silica in all the rocks of the Conception Group and to its strong resistance to erosion.

The two lowest formations of the Conception Group, the Mall Bay Formation and the Gaskiers

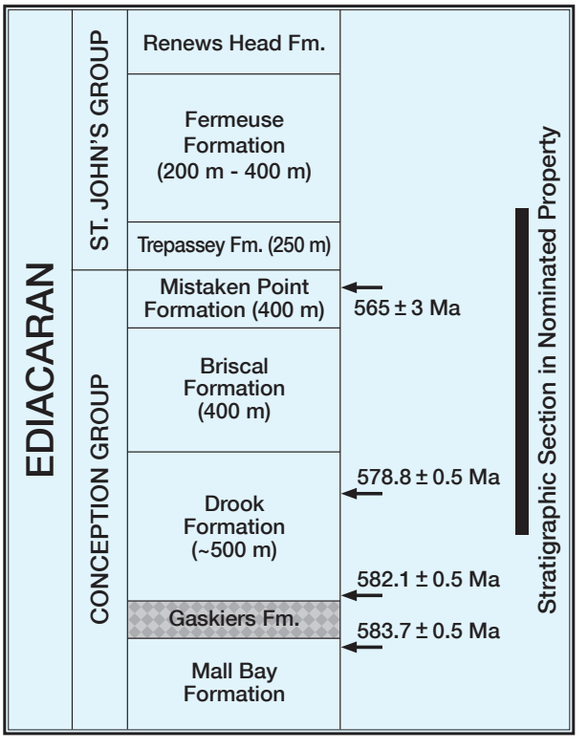


Figure 2.7. Ediacaran stratigraphic column for the southern Avalon Peninsula (after Williams and King, 1979) showing extent of the succession and formations (thickness in metres) within the nominated property and positions of key radiometric dates from ash horizons.

Formation (which contains glacial tillites), are both unfossiliferous and do not occur in the nominated property.[9] The upper three formations of the Conception Group are well exposed at Mistaken Point. The nominated property contains the type sections, in whole or in part, for all three of these formations:

Drook Formation: The Drook Formation is the thickest and most extensive sedimentary formation throughout the southern Avalon Peninsula.[2,9-11] It is approximately 1 kilometre thick, the uppermost 500 metres of which are exposed in the nominated property. This Formation consists of white weathering, grey- to greenish-coloured, siliceous siltstones and sandstones (Figures 2.3 and 2.6). Sandstone beds range from thin-bedded, distal turbidites to medium-bedded, more proximal turbidites. Volcanic ash is common throughout the Formation, with some beds up to 35 centimetres thick (Figure 2.8) and volcanic ejecta ranging from fine crystals to pea-sized lapilli.

Briscal Formation: The Briscal Formation is at least 400 metres thick in the nominated property. It is the coarsest-grained and thickest-bedded formation in the succession, and consists of proximal turbidites up to 1 metre thick stacked on top of each other or separated from each other by thin beds of mudstone (Figure 2.9). Dish structures and contorted bedding are abundant in these sandstones but slumped beds are unknown, implying rapid deposition on a flat sea bottom. Volcanic ashes are thin and far less common than in the Drook Formation.[5,9]

Figure 2.8. Thirty-five-centimetre-thick volcanic ash (light grey hue), overlying the well-known Pizza Disc Bed (reddish hue). Drook Formation, Pigeon Cove.

Figure 2.9. Briscal Formation sequence dominated by thick-bedded turbidite sandstones, west of Bristy Cove.

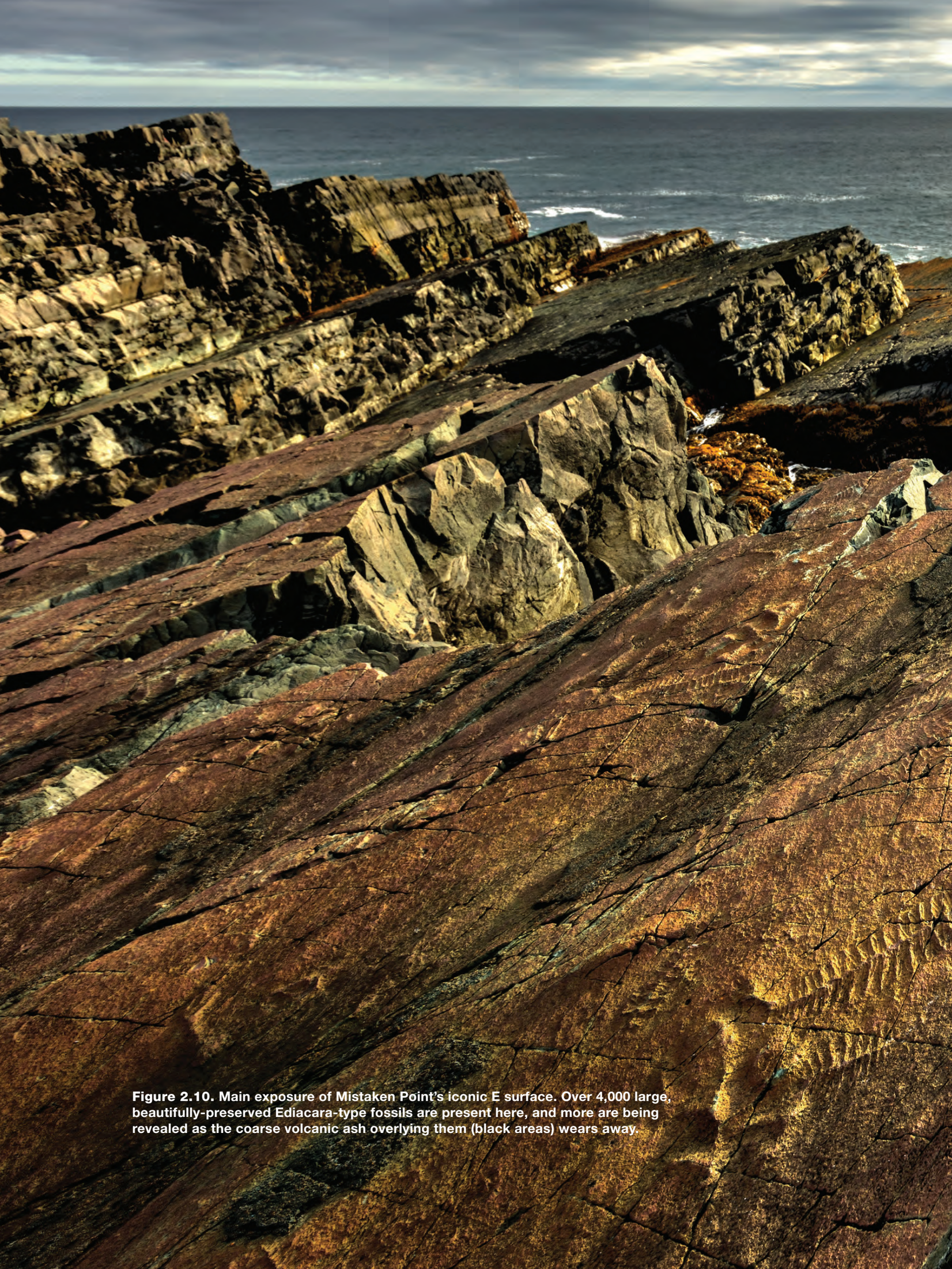


Figure 2.10. Main exposure of Mistaken Point's iconic E surface. Over 4,000 large, beautifully-preserved Ediacara-type fossils are present here, and more are being revealed as the coarse volcanic ash overlying them (black areas) wears away.

Figure 2.11. Upper Trepassey Formation sequence consisting of thinly interbedded sandstones and siltstones affected by slump structures, west of Shingle Head.

Mistaken Point Formation: This 400-metre-thick Formation consists of thin- to medium-bedded fine- to very fine-grained sandstones with rare thick-bedded, medium-grained sandstones (Figure 2.2). A distinctive feature is the presence of purple-red and greyish red mudstone units that, within the nominated property, are restricted to this Formation.[7] According to Wood et al.,[7] "hundreds if not thousands" of thin layers of volcanic ash (crystal tuffs and tuff-rich beds) occur throughout the Mistaken Point Formation, and this is reflected in the extreme abundance of Ediacara-type megafossil impressions in this Formation (Figure 2.10).

Stratigraphy of the St. John's Group

The St. John's Group consists mainly of very thin-bedded turbiditic sandstones separated by thick beds of dark mudstone. Volcanic beds and debris are rare, and the corresponding lack of silicification has resulted in strata that are much more prone to erosion than those of the underlying Conception Group. The two lowermost formations of the St. John's Group are exposed in the nominated property:

Figure 2.12. General view of the Fermeuse Formation section on the west side of Shingle Head.

Trepassey Formation: The Trepassey Formation gradationally overlies the Mistaken Point Formation.[9,12] It is about 250 metres thick and consists of grey-green, very thin- to thin-bedded fine sandstones and mudstones[7,9] (Figure 2.11). Silty mudstones comprise 60 to 80 percent of this Formation. Large-scale soft-sediment deformation is ubiquitous and includes slump complexes up to 65 metres thick. Volcanic crystal tuffs are few and thin.[7]

Fermeuse Formation: This is the most widespread and thickest formation in the St. John's Group on the Avalon Peninsula, but only its basal 200 to 400 metres are visible in the nominated property (Figure 2.12). The Fermeuse Formation consists of dark brown to black, very thinly interbedded silty mudstones and very fine-grained sandstones. Large slump structures are abundant throughout the Formation.

Depositional Setting

The various depositional environments represented by the Ediacaran succession of the Avalon Peninsula reflect an overall shallowing-upward trend that began with the deep-sea deposits of the Conception and St. John's groups (Figure 2.7) and culminated in the terrestrial deposits of the Signal Hill Group[5-7,13-18]. Most of the Ediacaran strata at Mistaken Point accumulated in an elongate, northeast-southwest-oriented, deep-marine basin, adjacent to a tectonically active volcanic island arc.[7,14-16,18]

The main sedimentary processes responsible for deposition of the entire nominated succession were turbidity currents,* contour currents,† submarine debris flows, and hemipelagic settling of fine suspended sediment. Turbidites are volumetrically the most important components of all five formations comprising this succession[2,4-7] (Figure 2.13).

Contorted beds are common in all formations, but slumps and submarine debris flows are common only in the Mistaken Point, Trepassey, and Fermeuse formations. This is generally taken as an indication that these younger formations were deposited on a deepwater slope (Figure 2.14).

With one exception—Retallack[8], who regarded the entire succession as deposited in coastal plains and intertidal zones—all previous researchers have independently concluded that the Drook Formation-to-Trepassey Formation succession within the nominated property was laid down at depths of hundreds of metres to more than one kilometre below

* Turbidity currents are dense, turbulent, sediment-water slurries that flow down the continental slope onto the deep marine basin; their deposits are termed "turbidites."

† Contour currents are gentle currents that flow parallel to the contours of the basin margin slope; their deposits are termed "contourites."

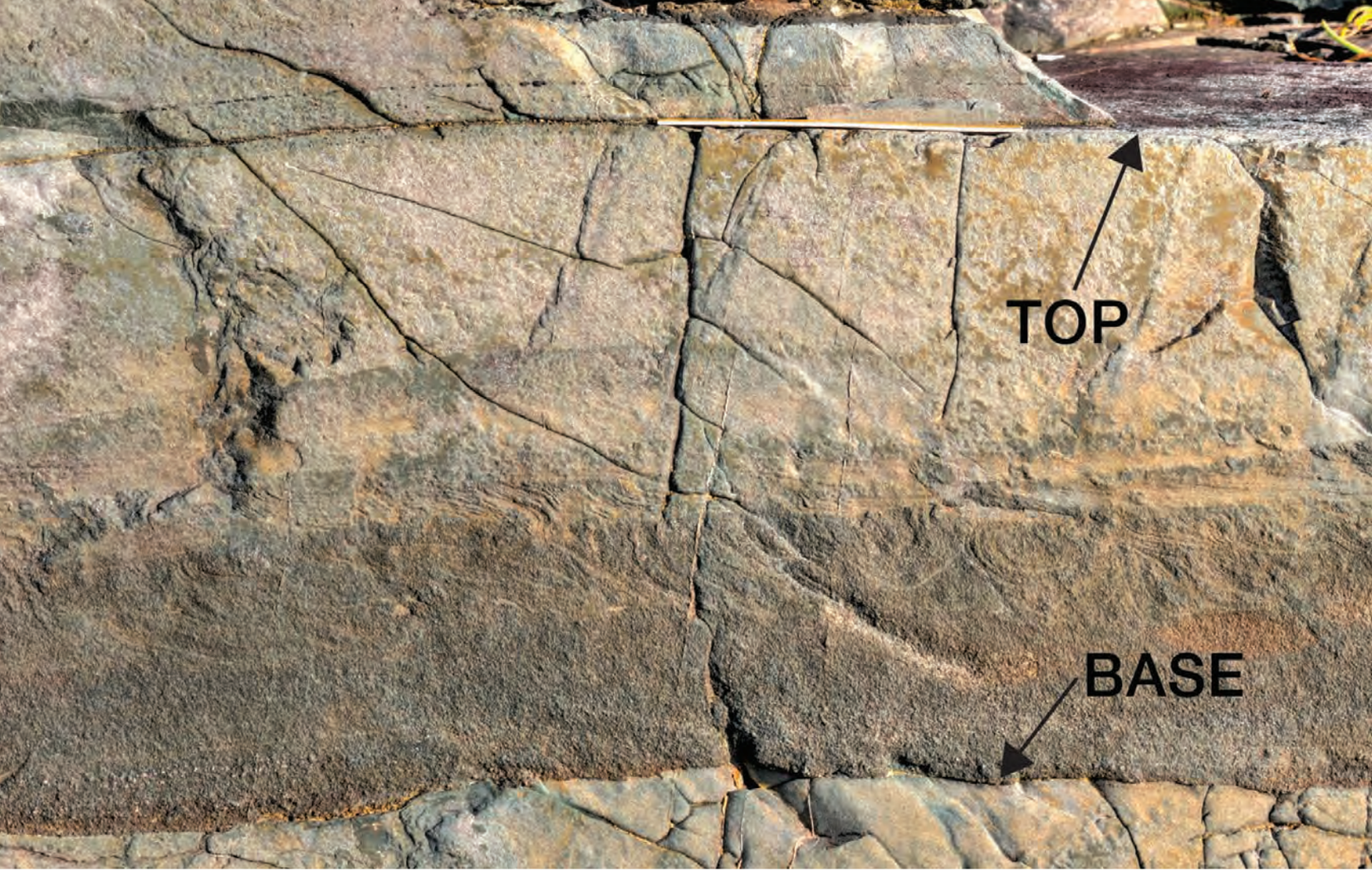


Figure 2.13. Thin (18 cm), normally-graded, sandstone-to-mudstone turbidite in the upper Mistaken Point Formation. This turbidite overlies a basal erosion surface and its upper bedding plane (top) bears an assemblage of trace fossils (see Figure 2.44). Also visible are small-scale (ripple) cross- and convolute lamination.

the ocean surface, well below storm wave base and the lower limit of the photic zone.[2,3,5-7,14] In other words, Mistaken Point's communities of organisms thrived in the cold, lightless, high-pressure environment of the deep-sea floor.

Structural Geology

Mistaken Point is part of the Avalon Zone[14,19-22] (Figure 2.15), a belt of deformed Neoproterozoic to early

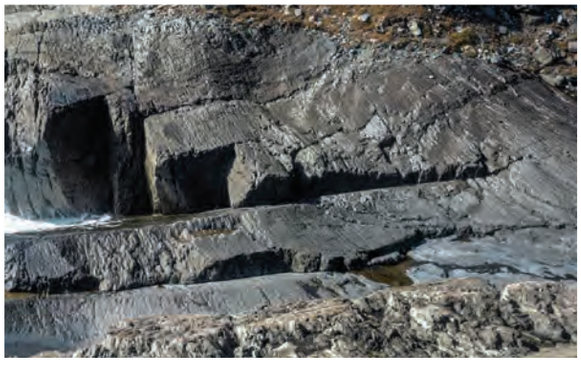


Figure 2.14. Soft-sediment deformed, megafossil-bearing bedding plane near the top of the Trepassey Formation, west of Shingle Head.

Figure 2.15. Map showing the extent of the Avalon Zone (tectono-stratigraphic terrane) in eastern Newfoundland (after Myrow, 1995).

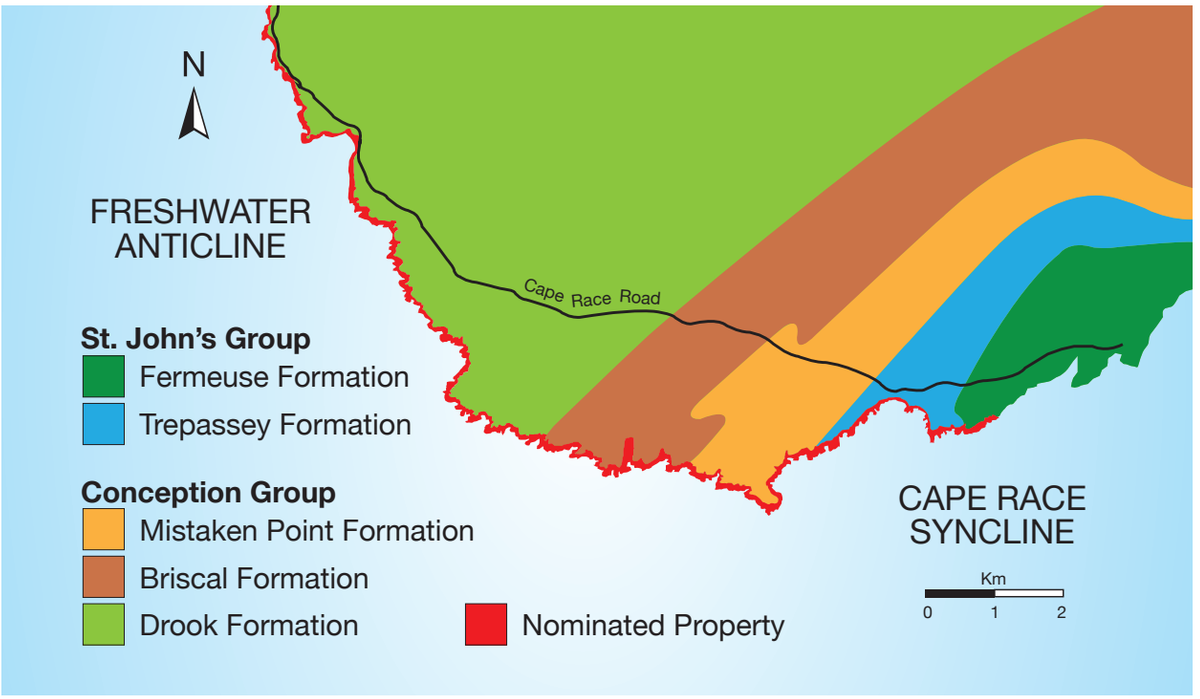


Figure 2.16. Geological map of the nominated property and its hinterland (modified from Williams and King, 1979; King, 1988; and Misra, 1971).

Figure 2.17. Anticline-syncline pair of small, upright, parasitic folds located about one kilometre west of Mistaken Point itself.

Paleozoic strata that underlie most of eastern Newfoundland and extend at least as far south as Boston. Structures in the nominated property are mainly open folds and associated faults. Most major structures trend approximately northeast–southwest,[9,11] which is roughly perpendicular to the strike of much of the coastline. The axis of the Freshwater Anticline intersects the coast near The Drook, and the oldest rocks and fossils in the nominated property occur in the core of this fold. Strata exposed at the surface become progressively younger away from the anticlinal axis, and a complete section extends from the Drook Formation in the core of the Freshwater Anticline eastward along the coast to the Fermeuse Formation in the core of the Cape Race Syncline (Figure 2.16).

Dips of the strata are typically 5 to 25 degrees (Figure 2.6), with steeper dips on some of the minor folds (Figure 2.17). The strata are disrupted by both normal and reverse faults (Figure 2.18), but distinctive marker beds permit precise correlation across most of these faults.[7] Tectonic repetition of some key fossil beds, principally the renowned D and E surfaces (which possess the highest abundance and diversity of fossils in the nominated property) enables researchers to see the same fossil bed in different locations, and this helps to elucidate the spatial distributions of the organisms comprising these early deep-sea communities.[23]

Associated with the folds is a penetrative, spaced, pressure solution, axial-planar cleavage (Figure 2.19) that has shortened the strata by 0 to 50 percent (average approximately 42 percent[6]). This shortening has modified the shapes and angular relations of all Mistaken Point fossils, but these effects can be redressed mathematically or photographically through the process of retrodeformation[7,24] (see Figure 2.72 in Section 2.b (iii)). The rocks in the nominated property have also been subjected to very low grade, zeolite-facies metamorphism, but this has not adversely affected the preservation quality of the Ediacaran megafossils.

Age

The nominated property is unique among Ediacaran sites worldwide in its abundance of beds of volcanic ash[7]

Figure 2.18. Gully eroded along the trace of the high-angle fault running across the base of the Mistaken Point promontory.

(Figure 2.8). These beds played a critical role in preserving the Ediacaran megafossil impressions. Crystals of the mineral zircon within these ashes (Figure 2.20) can be used to obtain high-precision, U-Pb (uranium-lead), radioisotopic dates to determine the age of the fossils in this succession. The first Ediacaran fossil assemblage dated by radioactive decay anywhere in the world was the famous E surface in the Mistaken Point Formation (Figures 2.7, 2.2, and 2.10). This surface directly underlies an ash layer (Figure 2.21) that yielded a date of 565 ± 3 million years.[3,25-27] A subsequent date of 578.8 ± 0.5 million years for an ash (Figure 2.8) overlying the Ediacaran discs and small fronds on the Pizza

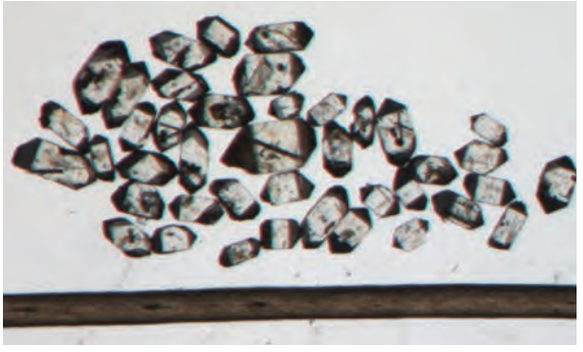


Figure 2.20. Pristine (first-cycle) zircon crystals extracted from a volcanic ash within the nominated property. Human hair for scale.

Figure 2.19. View parallel to the trend of a pressure solution cleavage oriented perpendicular to the main D surface bedding plane. In the past, the positive (weathering) relief of these spaced cleavage plane "clumps" led to their misidentification as wave ripples.

Figure 2.21. Volcanic ash overlying the E surface near Mistaken Point. Erosion of the ash is forming a slot immediately above this fossil-rich former deep-sea floor.

Disc Bed in the upper Drook Formation[26,27] provides a key age constraint on the world's oldest- and largest-known, complex Ediacaran megafossils, which occur approximately 200 metres lower (and thus earlier) in the succession. U-Pb dates of 582 to 584 million years ago obtained elsewhere in Newfoundland for the end of the Gaskiers Glaciation[26,28] imply that the earliest complex Ediacara-type megafossils in the Drook Formation of the nominated property postdate the end of this Ediacaran glaciation by less than 3 million years (Figure 2.7). Zircons from other ashes within Mistaken Point's nominated sequence have been dated by multiple laboratories in Canada, the United States, and Britain.

Given the stratigraphic position of these dated units, the age range for the nominated property's entire stratigraphic succession is approximately 580 to 560 million years ago.[28] This time interval corresponds to Stage-level division 2 in the preferred correlation of the Ediacaran Period in the Geologic Time Scale 2012[28] and the term "middle Ediacaran" is used for this time interval throughout this dossier (Figure 2.22).

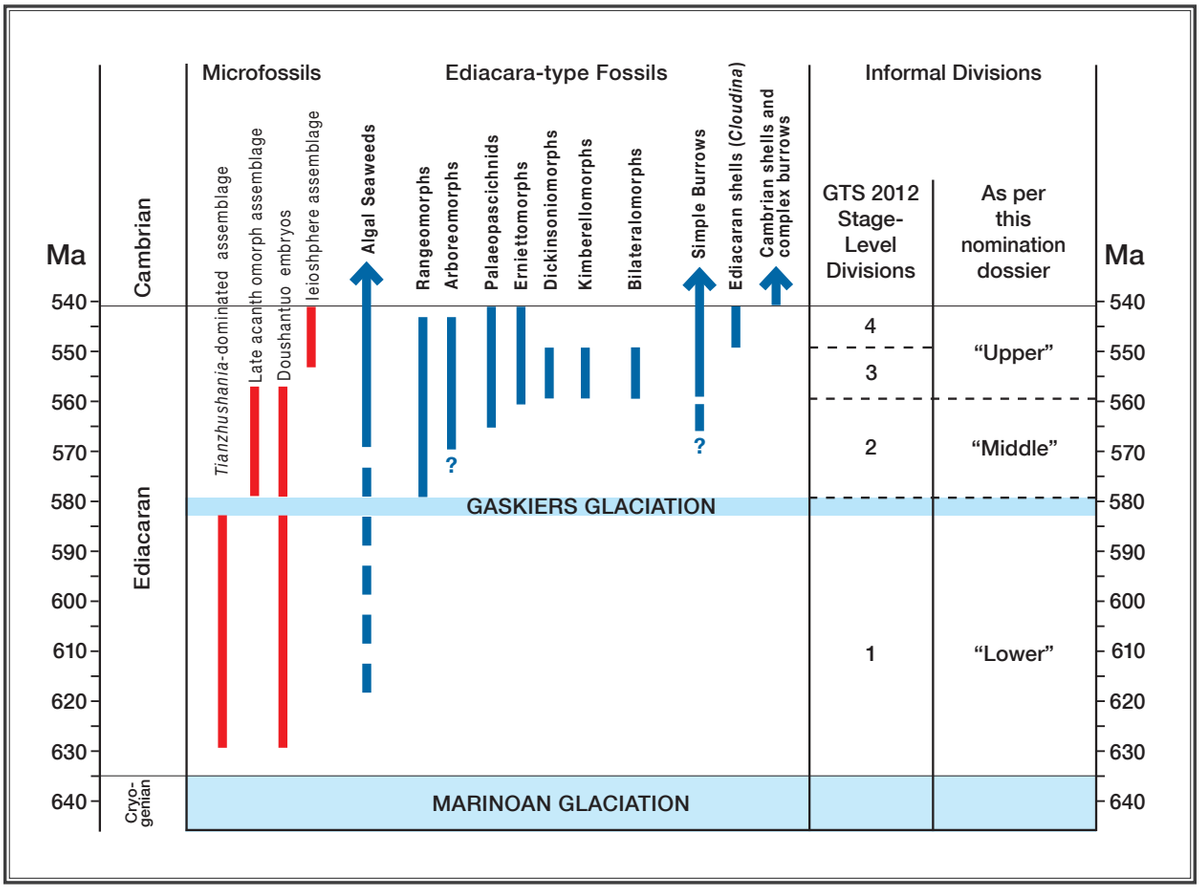


Figure 2.22. Stratigraphy of the Ediacaran Period. The nominated property encompasses most of the middle Ediacaran (after Narbonne et al., 2012, figure 18.6); Ma = Million Years Ago

2.a (iii) The Fossil Record

Diversity and Biological Affinities

The Ediacaran megafossils at Mistaken Point are a preservational type technically termed "Ediacara-type fossils"—soft-bodied creatures that were preserved as impressions beneath event beds of sandstone or volcanic ash.[29] —that provide the main record of megascopic Ediacaran fossil life worldwide. The affinities of these megafossils are controversial, with published views that span virtually the entire spectrum of life; but most current researchers believe that they represent ancestral, stem-group animals—extinct branches off the lineage that led to modern animals.

Seventeen species belonging to 14 genera are known from Mistaken Point. Most Mistaken Point fossils cannot be related to any living groups of organisms and appear instead to represent extinct clades of stem-group animals near the base of complex multicellular life. One fossil species may represent an early sponge-like organism. Three distinct taxonomic groups can be recognized at Mistaken Point: Group Rangeomorpha (Figures 2.23-2.37), Group Arboreomorpha (Figures 2.38, 2.39) and Phylum Porifera (?) (Figure 2.40). These are listed along with the named genera and species known from Mistaken Point.

Group Rangeomorpha (Pflug, 1972)

Avalofractus abaculus,
Narbonne, Laflamme, Greentree, and Trusler, 2009[30] (Figure 2.23)

Beothukis mistakensis,
Brasier and Antcliffe, 2009[31] (Figures 2.24 and 2.35)

Bradgatia linfordensis,
Boynton and Ford, 1995[32] (Figures 2.25 and 2.35)

Charnia masoni,
Ford, 1958[33] (Figure 2.26)

Culmofrons plumosa,
Laflamme, Flude, and Narbonne, 2012[34] (Figure 2.27)

Fractofusus andersoni,
Gehling and Narbonne, 2007[35] (Figures 2.28 and 2.35)

Fractofusus misrai,
Gehling and Narbonne, 2007[35] (Figures 2.29 and 2.35)

Frondophyllas grandis,
Bamforth and Narbonne, 2009[36] (Figure 2.30)

Hapsidophyllas flexibilis,
Bamforth and Narbonne, 2009[36] (Figures 2.31 and 2.35)

Pectinifrons abyssalis,
Bamforth, Narbonne, and Anderson, 2008[37] (Figure 2.32)

Primocandelabrum hiemaloranum,
Hofmann, O'Brien and King, 2008[38] (Figure 2.45)

Trepassia (Charnia) wardae,
Narbonne and Gehling, 2003[39] (Figure 2.33)

Vinlandia (Charnia) antecedens,
Laflamme, Narbonne, Greentree, and Anderson, 2007[40] (Figure 2.34)

Figure 2.23. Reconstruction of *Avalofractus abaculus*, by Peter Trusler.

Figure 2.25. *Bradgatia linfordensis*, a bush-shaped rangeomorph.

Figure 2.24. The type specimen of *Beothukis mistakensis*, a rangeomorph frond, on the E surface near Mistaken Point.

Figure 2.26. *Charnia masoni*, a wide-ranging rangeomorph frond that occurs through much of the succession at Mistaken Point and is also known from Ediacaran fossil assemblages in England, Russia, Australia, and western Canada.

Figure 2.27. *Culmofrons plumosa*, a rangeomorph frond.

Figure 2.28. The holotype of *Fractofusus andersoni*, an oblate rangeomorph spindle from the Briscal and Mistaken Point Formations.

Figure 2.29. *Fractofusus misrai*, an elongate rangeomorph spindle from the upper part of the Mistaken Point Formation.

Figure 2.30. *Frondophyllas grandis*, a rangeomorph frond that stood nearly a metre high.

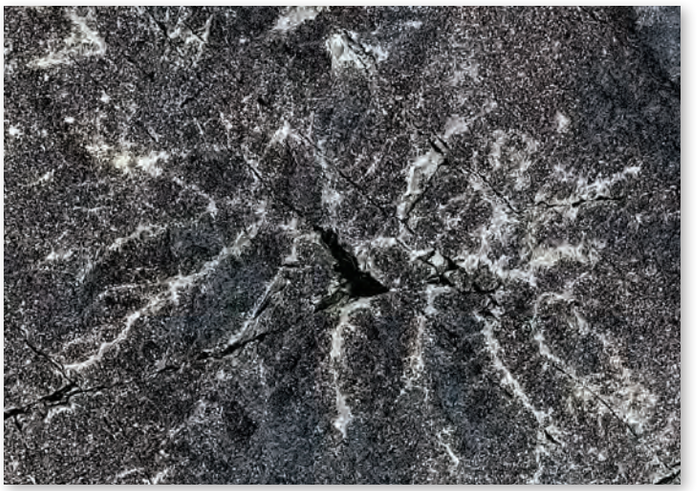


Figure 2.31. *Hapsidophyllas flexibilis*, a multi-branching rangeomorph network.

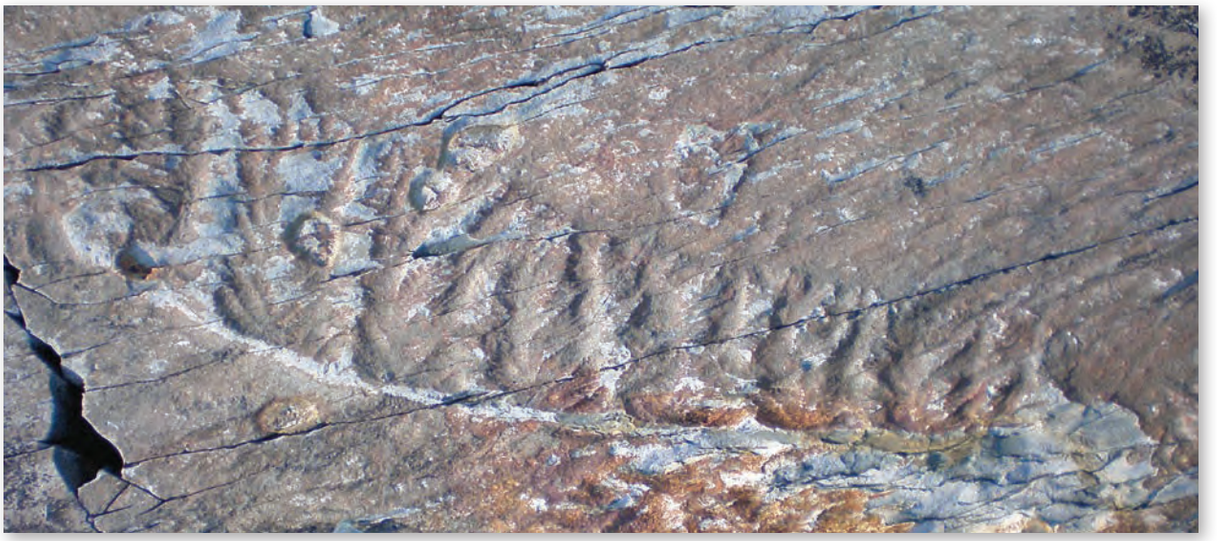


Figure 2.32. *Pectinifrons abyssalis*, a palisade of rangeomorph frondlets.

Figure 2.34. *Vinlandia (Charnia) antecedens,* a small rangeomorph frond from the Drook formation that occurs below a volcanic ash dated at 578.8 million years old.

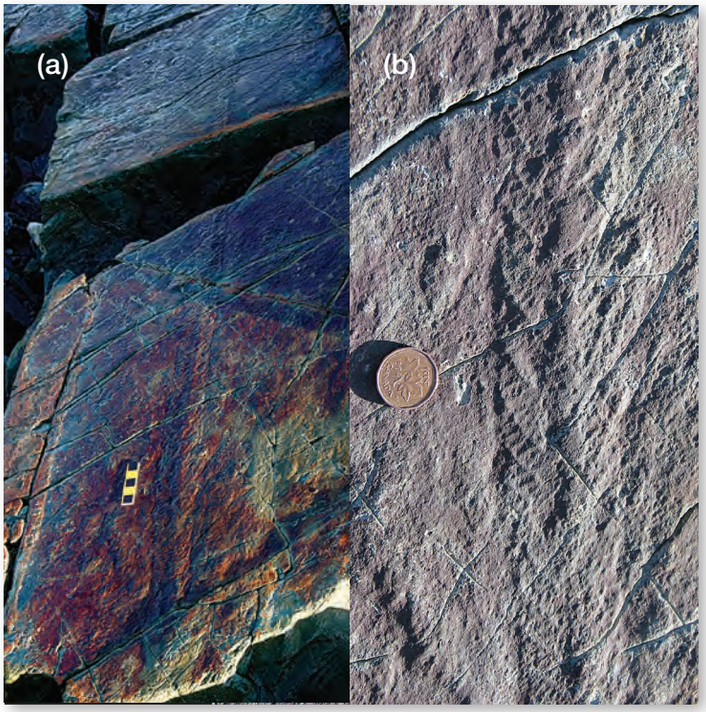


Figure 2.33. *Trepassia (Charnia) wardae*, a rangeomorph frond that is the oldest large and architecturally complex fossil known anywhere; (a) this 1.65 metre-long specimen from the Drook Formation occurs 200 metres below a volcanic ash dated at 578.8 million years old; (b) detail of the microstructure of the *Trepassia (Charnia) wardae* frond shown in (a).

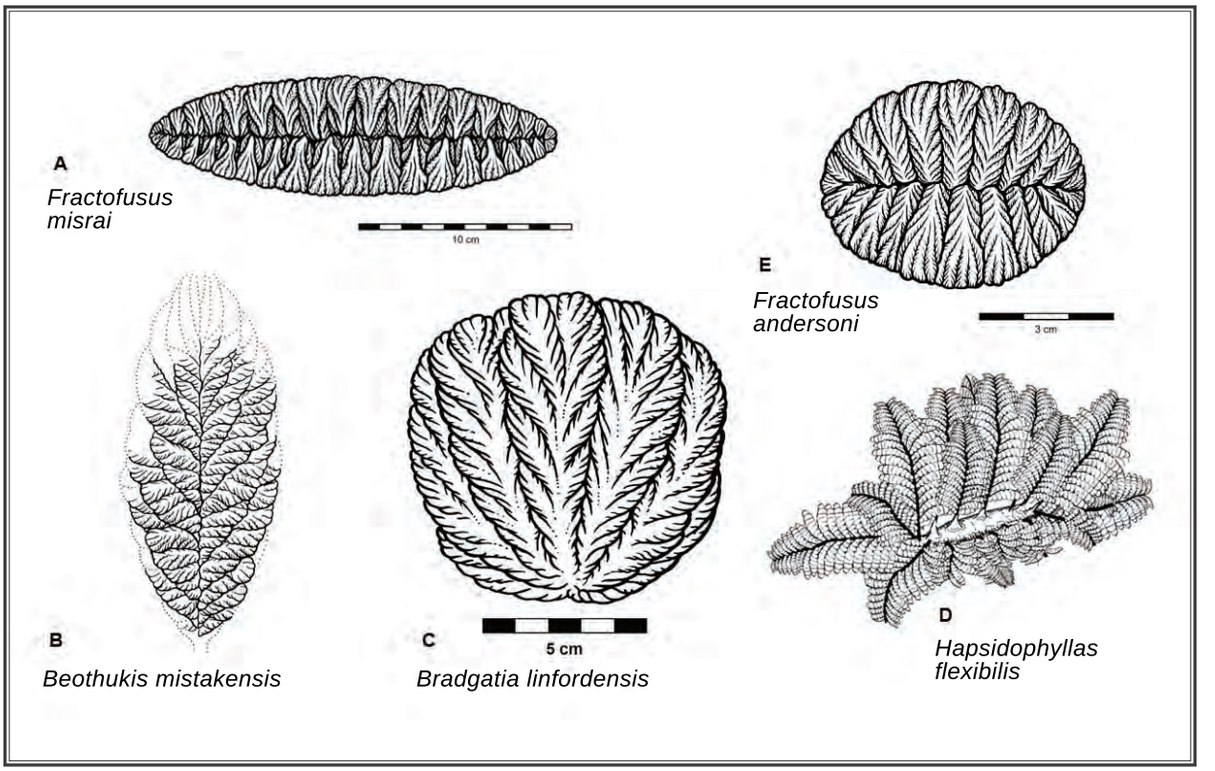


Figure 2.35. Line drawings and reconstructions of the rangeomorph taxa from the Mistaken Point Formation: (a) *Fractofusus misrai* and (e) *F. andersoni* (from Gehling and Narbonne, 2007); (b) *Beothukis* (from Narbonne et al., 2009); (c) *Bradgatia* (from Flude and Narbonne, 2009); (d) *Hapsidophylla*s (from Banfield and Narbonne, 2009).

Most of the Ediacaran taxa and specimens in the nominated property are classified as rangeomorphs (Figures 2.23 to 2.37), a group that dominated middle-Ediacaran life worldwide but became extinct before the end of the Ediacaran Period. Mistaken Point contains the greatest abundance and diversity of rangeomorph fossils anywhere, and more than 75 percent of all Ediacaran fossil individuals and species at Mistaken Point are rangeomorphs.[41] The spindle-shaped rangeomorph *Fractofusus* is the most common fossil at Mistaken Point, with literally thousands of specimens documented on the classic D and E surfaces.[23]

Rangeomorphs are distinguished by centimetre-scale architectural elements exhibiting self-similar (fractal) branching patterns[42] (Figure 2.36) that were combined as modules to produce decimetre- to metre-scale constructions (Figure 2.37). These elements could be arranged in different orientations that were consistent within individual species[30,31,43] that would have affected how the fractal branches were exposed to the seawater that surrounded them. Variations on these simple architectural and constructional rules produced the wide array of rangeomorph growth forms and taxa that dominated the middle Ediacaran sea floor worldwide.

Earlier researchers regarded rangeomorphs as primitive radial animals such as cnidarians[2,44] or ctenophores,[45] but most modern researchers regard them as an extinct clade near the base of animal evolution.[30,31,42,43,46-54] Rangeomorphs lacked muscles, mouths, or guts,[42] and are believed to have used their highly fractal structure to feed by absorbing organic molecules through their skin (osmotrophy).[55,56] They are especially common and diverse in deepwater, middle Ediacaran strata,[28.50,51] probably because of an abundance of dissolved organic compounds at depth in the Ediacaran oceans.[57] Rangeomorphs also occur in shallower-water, upper Ediacaran assemblages from Russia, Australia, and Namibia but they are much less common, considerably less diverse, and greatly overshadowed in these younger assemblages by erniettomorphs, dickinsoniomorphs, and other typically shallow-water fossils.[58] Growth by modular construction of fractal elements could be accomplished with a minimum of genetic information, and this may have been a factor in the quick ascent and mid-Ediacaran dominance of rangeomorphs followed by their gradual fading away during the late Ediacaran.[42,59]

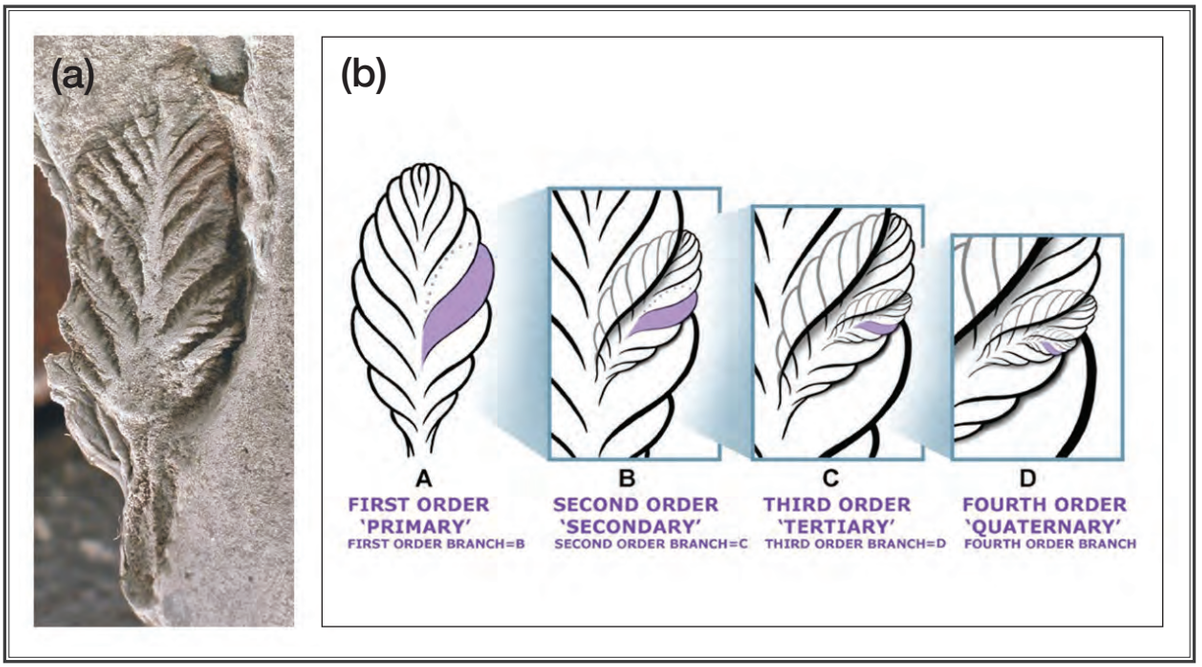


Figure 2.36. Rangeomorph architecture: elements showing self-similar branching over several fractal orders; (a) fossil element (from Narbonne, 2004) and (b) interpretation of the self-similar architecture (from Narbonne et al., 2009).

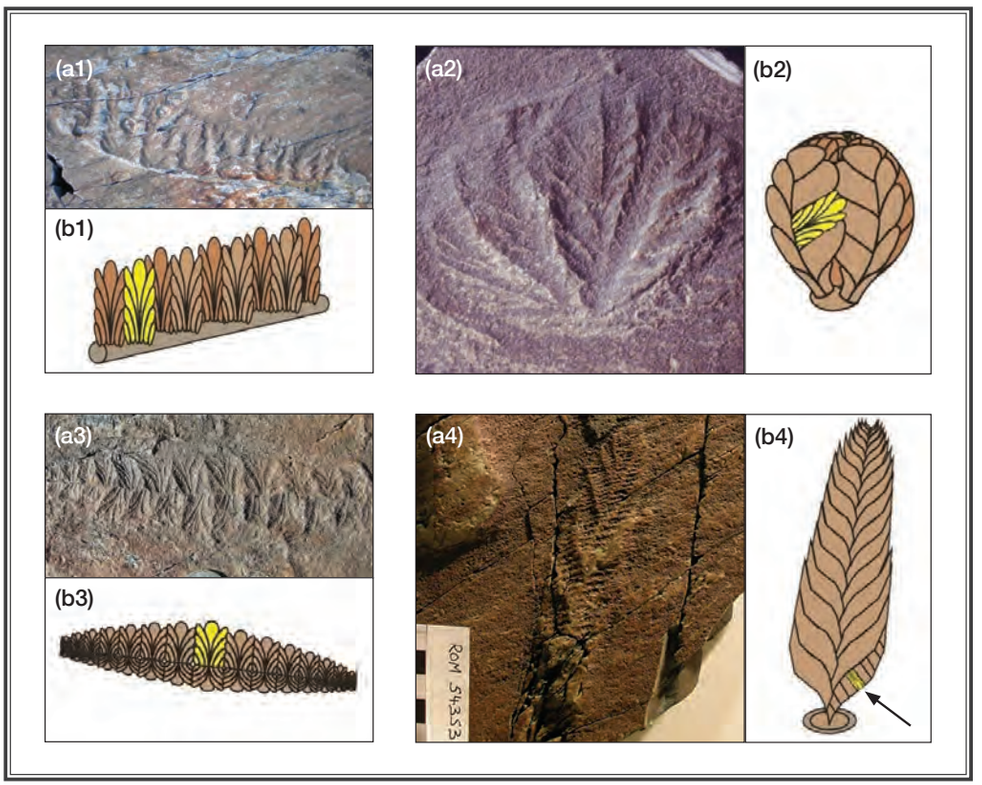


Figure 2.37. Rangeomorph construction: individual rangeomorph elements (example shown in yellow) combined as modules to build larger structures (complete organism shown in brown) such as: 1. The palisade rangeomorph *Pectinifrons* (see Fig. 2.32); 2. the bush-shaped rangeomorph *Bradgatia* (see Fig. 2.25); 3. the spindle-shaped rangeomorph *Fractofusus misrai* (see Fig. 2.29); 4. the frondose rangeomorph *Charnia* (see Fig. 2.26) (from Laflamme and Narbonne, 2008).

Group Arboreomorpha (Xiao and Laflamme, 2009)

Charniodiscus (Arborea) arboreus,
Glaessner *in* Glaessner and Daily, 1959[60] (Figure 2.38)

Charniodiscus spinosus,
Laflamme, Narbonne, and Anderson, 2004[61] (Figure 2.39)

Charniodiscus procerus,
Laflamme, Narbonne, and Anderson, 2004[61] (Figure 2.39)

This clade encompasses Ediacaran fronds that possess primary branches that are stitched together into a large leaf-like sheet with tear-drop-shaped secondary branches[52,54] (Figure 2.38). Taxa include *Charniodiscus* plus similar forms that are closely related or synonymous with this genus. Arboreomorphs occur most commonly from about 570 to 545 million years ago in a variety of deep- and shallow-water Ediacaran facies, including Charnwood Forest in England and the Ediacara Hills in Australia. Earlier researchers emphasized the similarities between *Charniodiscus* and modern frond-shaped Cnidaria,[62] but it is more likely that the similar frond morphology reflects a similar life habit rather than a shared ancestry.[63,64]

Arboreomorphs are common at Mistaken Point. A possible specimen has been figured from the Drook Formation, but the greatest abundance and diversity is in the Mistaken Point Formation. *Charniodiscus* probably fed similarly to rangeomorph fronds, but differed in suspending a feeding basket at the end of a smooth stem rather than having feeding apparatuses along its entire length.[65]

Phylum: Porifera (?)

Thectardis avalonensis,
Clapham, Narbonne, Gehling, Greentree, and Anderson, 2004[66] (Figure 2.40)

Thectardis was a centimetre-scale hollow cone (Figure 2.40) that was named and described from Mistaken Point[66] and was subsequently reported from Charnwood Forest in England.[67] Its overall shape is highly reminiscent of a sponge (Porifera), the simplest and most primitive animal phylum in our modern world, but this attribution is tentative since none of the fine pores that characterize modern sponges are visible in these Mistaken Point fossils.[57] *Thectardis* was a low-level suspension feeder or osmotroph that lived with its apex stuck in the sediment.

Other Fossils

Most Ediacaran assemblages worldwide contain abundant discs that were formerly regarded as fossil jellyfish.[68,69] *Aspidella* (Figure 2.41), originally described from eastern Newfoundland by Billings in 1872[70], and *Hiemalora* (Figure 2.42), first described from northern Russia, probably represent the attachment discs of unpreserved fronds such as *Charniodiscus* and *Primocandelabrum*.[38,68] The enigmatic Pizza Disc fossil *Ivesheadia* (Figure 2.43) has been variably interpreted as a degraded Ediacaran megafossil,[71] a microbial colony,[72] or a sedimentary structure reflecting burial of a frond in a turbidite.[67] These discs do not represent biological species and are instead generally referred to as "form taxa." As such these discs are not included in the fossil diversity for Mistaken Point or for other Ediacaran localities worldwide.[73]

Figure 2.38. *Charniodiscus arboreus*, an arboreomorph frond.

Fossilized surface trails with crescentic internal divisions occur high in the Mistaken Point Formation (Figure 2.44) and have been interpreted as the locomotion trails of cnidarians.[74,75] These are the only trace fossils known from Mistaken Point or any other localities of this age, and thus probably represent the oldest definite evidence of mobile animals in the evolution of life on Earth.

High Quality of Preservation

In contrast with the fossil record of younger Phanerozoic periods (Cambrian to Recent), which are dominated by shells, bones, and wood, the Ediacaran fossil assemblages at Mistaken Point and elsewhere worldwide are overwhelmingly dominated by impressions of soft-bodied, mostly immobile life forms. These creatures were preserved when they were instantaneously covered by event beds—sand deposited from storms and turbidites or ash falls from volcanic eruptions—that entombed the living community of soft-bodied creatures and preserved them as impressions on the bases of these event beds.

Figure 2.39. Detail of the Mistaken Point E surface with abundant arboreomorph and rangeomorph fossils. Two specimens of *Charniodiscus spinosus* (bottom left and top right) and two specimens of *Charniodiscus procerus* (centre) were knocked down by a current flowing from the top to the bottom of the picture (see Laflamme et al., 2004). Note abundant specimens of the rangeomorph spindle *Fractofusus* (some partly ripped up by the current, some covered by felled *Charniodiscus* fronds) and a single specimen of the rangeomorph frond *Beothukis* (center left). The volcanic ash that covered this fossil assemblage (visible as a thin bed at the bottom of the picture) has been directly dated at 565 ± 3 million years, providing a precise date for this moment in the Ediacaran history of Mistaken Point.

Figure 2.40. *Thectardis avalonensis*, a conical organism that may be an ancestral sponge.

Figure 2.41. *Aspidella terranovica*, the attachment disc of *Charniodiscus* and other fronds.

Figure 2.42. *Hiemalora stellaris*, the attachment disc of *Primocandelabrum* and other fronds.

Figure 2.43. The enigmatic "pizza disc" *Ivesheadia lobata*.

Figure 2.44. Surface trail of a mobile animal, possibly a cnidarian.

In contrast with the sandstone preservation that characterizes most Ediacaran fossils worldwide, Conception-style preservation under beds of volcanic ash[59,76,77] is restricted to Avalonian localities in Newfoundland and England, and is best known from the Conception Group at Mistaken Point. In Conception-style preservation, communities of soft-bodied Ediacaran creatures living on the muddy sea bottom were buried by volcanic ash falls that exquisitely moulded the overall shape and fine features on the upper surfaces of the Mistaken Point organisms before they decayed[59,76,77] (Figures 2.21 and 2.29). The ash hardened quickly, and then mud from the sea floor beneath filled the cavities left by the gradually decaying organisms, producing a replica of the original sea floor on the top of the mudstone bed beneath the volcanic ash. In contrast with the highly resistant, silicified mudstones, the ash is unstable and erodes easily; at Mistaken Point this modern erosion has revealed tennis-court-sized surfaces of mudstone, each embossed with the impressions of hundreds to thousands of Ediacara-type megafossils preserved on these surfaces (Figure 2.10). Preservation under the volcanic ash beds at Mistaken Point has faithfully replicated the external morphology of the Mistaken Point organisms, with morphological features as small as 0.3 millimetres wide locally preserved on these surfaces. Fossils are preserved on the tops of beds where they can easily be observed and studied, not on the bottoms of beds as is typical of Ediacaran preservation in sandstone.

Comparison of Ediacaran fossil records throughout Newfoundland shows that maximum fossil diversity coincides with the peak abundance of beds of volcanic ash at Mistaken Point; this is a principal reason why Mistaken Point exhibits the highest diversity of any middle Ediacaran (580- to 560-million-year-old) fossil site worldwide.

Ecology: A Census Population

Conception-style preservation under beds of volcanic ash also provides critical information on fossil ecology that is not readily obtainable from other styles of Ediacaran preservation. The volcanic ash catastrophically covered the living community of sessile, soft-bodied organisms living on the muddy sea bottom, burying them in their original position on the sea floor. The organisms died where they lived in what has appropriately been called an "Ediacaran Pompeii."[24,76] Each such event produced what biologists and ecologists term a "census population," free from the effects of reworking and accumulation of hard parts that mask the ecology of most Phanerozoic assemblages of shells, bones, and wood. Looking at a Mistaken Point fossil

surface is like viewing a half-billion-year-old Ediacaran sea floor. This permits use of modern methods and analytical techniques in ecology[23,65,78] on fossil communities more than half a billion years old. Biological questions include the nature of tiering of different species above the sea bottom[65] (Figure 2.45), preferential intra- and inter-species distributions and spacing on the sea floor,[23] ecological succession following a kill event such as a turbidite or anoxia[65] (Figure 2.46), the role of spat falls on controlling fossil distribution and composition on the Ediacaran deep-sea floor,[78] and the modes of reproduction of Ediacaran rangeomorphs.[79] Three-dimensional reconstructions of Mistaken Point communities can be modelled

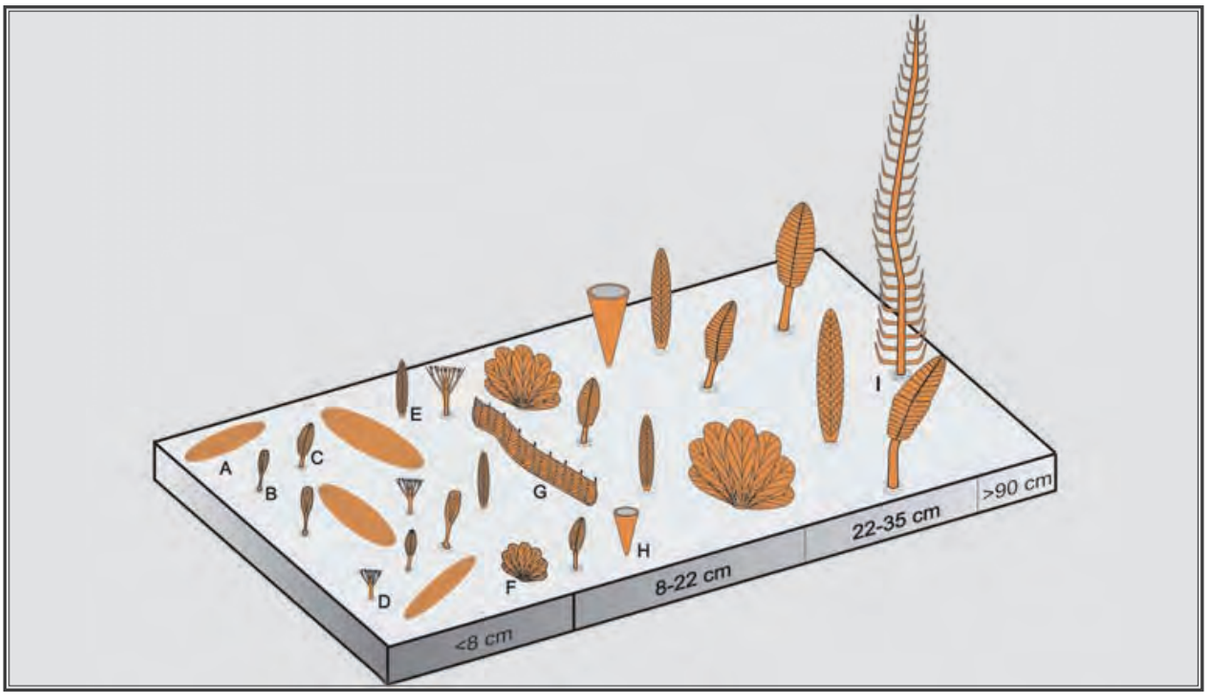


Figure 2.45. Tiering in the Mistaken Point ecosystem: (a) *Fractofusus*; (b) *Culmofrons*; (c) *Charniodiscus*; (d) *Primocandelabrum*; (e) *Charnia*; (f) *Bradgatia*; (g) *Pectinifrons*; (h) *Thectardis*; (i) *Frondophyllas*. All except for (c) and (h) are rangeomorphs (after Narbonne, 2005; and Clapham and Narbonne, 2002).

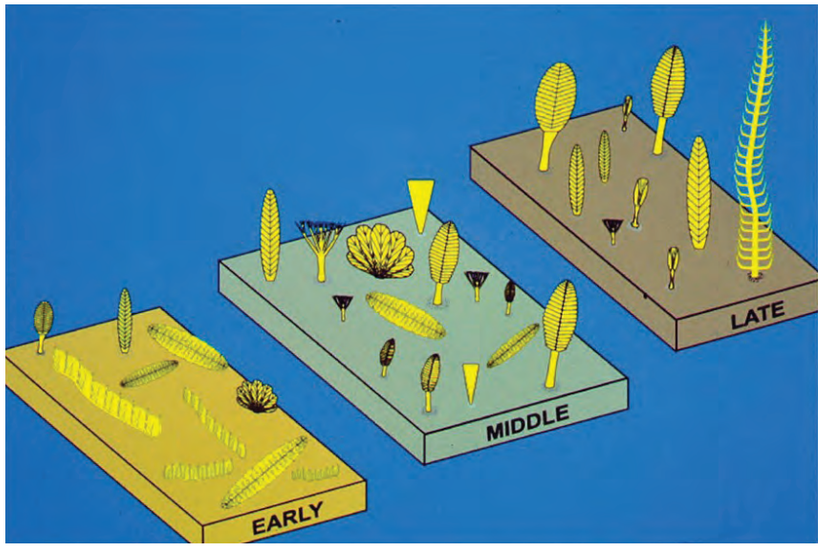


Figure 2.46. Ecological succession in the Mistaken Point ecosystem (after Clapham et al. 2003).

hydrodynamically to determine the nature of current flow that favoured the development of early complex life forms over the microbial mats that had dominated marine ecology for the preceding three billion years.[56]

Eight major fossil-bearing surfaces and more than 100 minor fossil-bearing surfaces punctuate the 2 kilometres of stratigraphy exposed in the nominated property. Each of these surfaces provides a snapshot of Ediacaran life, and these surfaces combine to tell the story of changes in evolution and ecology during the 20-million-year history recorded at Mistaken Point. Each of these volcanic ash beds contains zircons (Figure 2.20), which can provide a U-Pb date that precisely records the age of the fossil community that was simultaneously smothered and preserved by the ash. Dating of these surfaces has the potential

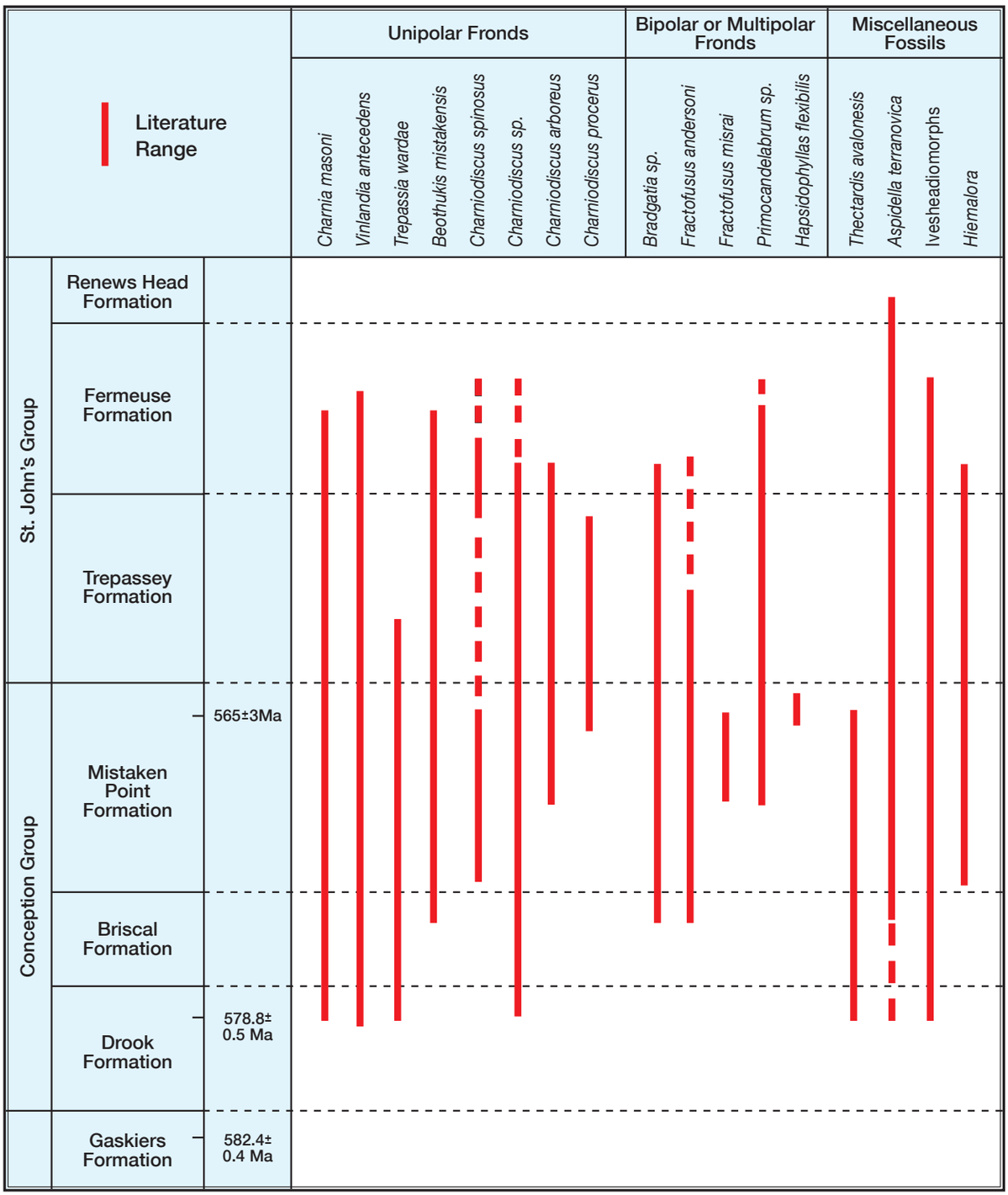


Figure 2.47. Stratigraphic distribution of the principal fossils in Newfoundland (after Liu et al., 2012).

to provide a precise chronology of evolution through this key 20-million-year interval in the early evolution of biological complexity, something that is not possible anywhere else on Earth.

Stratigraphy and Evolution

Fossils range throughout the entire 2-kilometre-thick succession in the nominated property, from *Thectardis* and *Ivesheadia* in the very lowest exposed beds of the Drook Formation in Pigeon Cove to *Aspidella* in the exposed beds of the Fermeuse Formation near Cape Race (Figure 2.47).

The oldest large and biologically complex fossils directly dated anywhere on Earth are the centimetre- to metre-scale fossils of the Drook Formation at Mistaken Point.[39] *Ivesheadia* (Figure 2.43) and numerous small fronds[80] (Figure 2.48) are cast by volcanic ash containing zircons dated at 578.8 ± 0.5 million years old[26] in the upper part of the Drook Formation, confirming the age of these key fossils. A fossiliferous interval 200 metres below this ash contains several specimens of the decimetre-scale frond *Vinlandia* (Figure 2.34), more than 100 specimens of the probable sponge *Thectardis*[66] (Figure 2.40), and nearly 100 specimens of the rangeomorph frond *Trepassia* (Figure 2.33). The presence of *Trepassia* fronds ranging in length from centimetre- to metre-scale throughout the Mistaken Point succession permits rigorous investigations of its growth and development.

Figure 2.48. Juvenile specimen of the rangeomorph frond *Charnia* from the Pizza Disc Bed in the Drook Formation. These fossils are 578.8 million years old.

The overlying Briscal Formation contains several new taxa that introduced new rangeomorph growth forms into the Mistaken Point biota—principally the cabbage-shaped fossil *Bradgatia* and the spindle-shaped recliner *Fractofusus*. The greatest diversity in the succession, and in any deepwater Ediacaran assemblage worldwide, is in the 565-million-year-old Mistaken Point Formation (Figure 2.49). Analysis of the tiering structure in this diverse assemblage, ranging from

Figure 2.49. The fossiliferous E surface in the Mistaken Point Formation at Watern Cove.

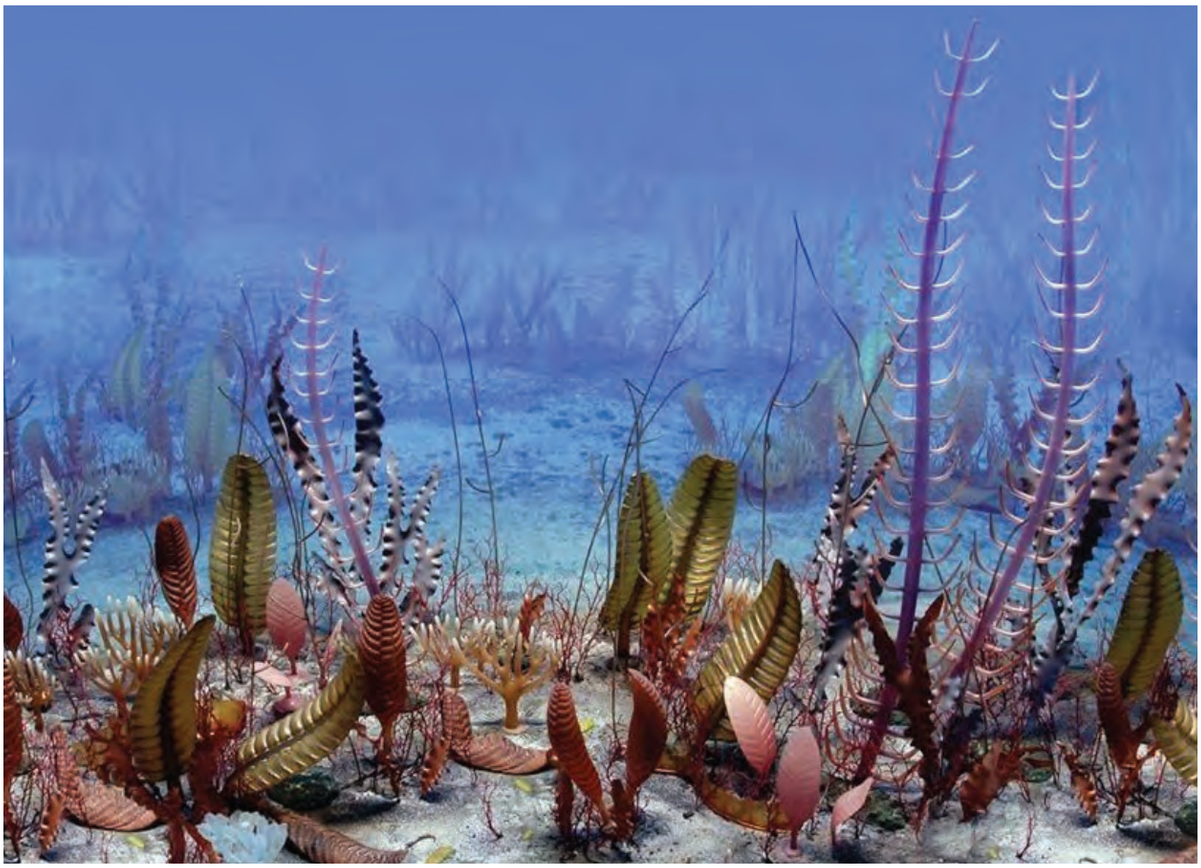


Figure 2.50. Reconstruction of the Mistaken Point sea floor. Image courtesy of Sam Noble Oklahoma Museum of Natural History, the University of Oklahoma.

surface-stickers like *Fractofusus* to *Frondophyllas* fronds that stood nearly 1 metre high (Figure 2.45), permits three-dimensional reconstruction of an Ediacaran sea-floor community (Figure 2.50).

Most of the Trepassey and Fermeuse formations at Mistaken Point lack volcanic ash and contain mainly simple discoid fossils (*Aspidella* and *Hiemalora*) preserved on the bases of sandstone beds. A single volcanic bed at the top of the Trepassey Formation overlies abundant rangeomorph fossils that exhibit Conception-style preservation on the top of the underlying mudstone bed. This distribution reinforces the important role of volcanic ash in the preservation of fossils at Mistaken Point.

Iron speciation is increasingly being used for paleo-oxygen (redox) determinations throughout the geologic timescale. Application of iron speciation to the fossiliferous strata at Mistaken Point shows evidence for a well-oxygenated water column, whereas all deepwater strata below the Drook Formation

Figure 2.51. View south across the barrens towards Freshwater Cove.

show evidence for dysoxia and anoxia in the water column.[81] U-Pb dates confirm that the abrupt change to a more oxygenated environment occurred at the top of the Gaskiers glaciation, only three million years before the appearance of large Ediacara-type fossils, suggesting environmental triggers for the appearance of the Mistaken Point fossils and potentially for the appearance of complex multicellular life in general.

2.a (iv) Environmental Setting

Ecoregion

The nominated property and its buffer zone lie within the island of Newfoundland's Eastern Hyper-oceanic Barrens ecoregion[82] (Figure 2.51). Inland of the nominated property, the barrens consist of a relatively thin, eroded and dissected veneer of glacial diamicton overlying the glaciated Precambrian bedrock.[83] Elevations range to a maximum height of 100 metres above sea level. Although the land is mostly covered by low-lying, heath-like vegetation, areas of weathered bedrock and boulder-grade felsenmeer can be found. The ground is uneven underfoot.

This ecoregion has a mid-boreal oceanic climate characterized by relatively short cool summers and fairly mild, wet winters. Climate data for St. Shotts (40 kilometres southwest of Portugal Cove South) are presented in Table 2.1.[84]

At Cape Race, to the east of the nominated property, prevailing wind directions are southwest (particularly in summer), but range from northwest through west and southwest to south, with an important northeast component, especially in winter. Carried ashore by the easterly and southerly winds, fog, that forms when moist air warmed by the Gulf Stream condenses over the cold Labrador Current, is frequent and persistent, averaging approximately 160 days per year (Figure 2.52). Fog is common in July and August. In spring the Labrador Current also brings icebergs, mostly calved from glaciers in western Greenland, to the waters off Mistaken Point. Wind speeds regularly exceed 120 kilometres per hour during severe storms.

The number and intensity of severe weather events varies from year to year, but both are predicted to increase as a result of global climate change (see Section 4.b (ii)). Mistaken Point's coastline is vulnerable to storm waves approaching from the west, southwest, south, and east. Major storm events most commonly occur between August and early October, when hurricanes travel up the Eastern Seaboard arriving in eastern Newfoundland as post-tropical storms (see Section 4.b (iii)). Blizzards are not uncommon during winter, and in late winter, coastal outcrops within the nominated property are often coated with sea-splash ice (Figure 2.53).

Figure 2.52. Fog is a common and distinctive feature of the southern Avalon Peninsula coast.

Figure 2.53. Sea-splash ice covering part of the Pizza Disc Bed outcrop at Pigeon Cove (March 2009).

Table 2.1. Climatic data for St. Shott's (after Thompson 2014).

CLIMATIC PARAMETER	MEAN VALUE
February temperature	-4.1°C
July temperature	13.3°C
Annual precipitation	1,548.1 mm
Annual rainfall	1,406.4 mm
Annual snowfall	141.7 mm

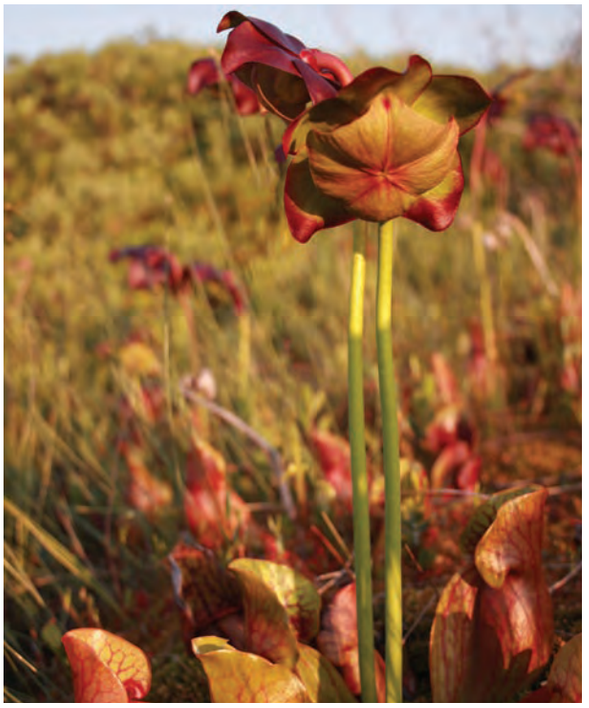


Figure 2.54. Pitcher Plant, the provincial flower of Newfoundland and Labrador.

Hydrology

The gently to moderately rolling topography of Mistaken Point Ecological Reserve is drained by innumerable minor streams and six significant, southwest- or south-flowing rivers—namely (from west to east) Pigeon Cove, Drook, Freshwater, Bristy Cove (by far the largest), Watern Cove, and Long Beach rivers. Blanket bogs are common and there are many small ponds.

Soils and Vegetation

Topsoil in the region is predominantly acidic, nutrient-poor, organic peat. While thicker in areas of blanket bog, the peat layer is generally thin and, if its vegetation cover is damaged or removed, is highly susceptible to erosion.

The barrens' glaciated landscapes support Arctic-alpine moss-heath and bog communities. At least 150 plant species have been recorded within Mistaken Point Ecological Reserve. A characteristic feature of the barrens, surviving only in valleys and depressions offering some shelter from the wind, are scattered patches of stunted Balsam Fir known in Newfoundland as "tuckamore." This is a landscape that, to borrow Wayne Lynch's memorable phrase, is "married to the wind."[85] The heath near Mistaken Point exhibits a ripple-like pattern and the grey, frost-killed southwest sides of these ripples identify the direction of the prevailing wind in winter.

The barrens support a diversity of fruit-bearing plants. Well-known examples include: Bakeapple (Cloudberry), Partridgeberry (Lingonberry), blueberry, cranberry, and Black Crowberry. With their evolution favoured by the barrens' nitrogen-poor soils, insectivorous plants such as sundews and Pitcher Plants are common. The Pitcher Plant is the provincial plant of Newfoundland and Labrador (Figure 2.54).

A variety of marine algae (seaweeds) thrive in Mistaken Point's intertidal zone and kelp beds grow well near the shore. Storm-tossed mounds of kelp fragments are a typical feature of beaches in the nominated property, especially at Long Cove and at the mouth of Watern Cove.

Wildlife

Birds

From The Drook eastward, the coastline of the nominated property falls within Canadian Important Bird Area (IBA) NF024.* The Mistaken Point IBA is globally significant for congregatory bird species because of its wintering populations of Purple Sandpipers and Common Eiders (Figure 2.55).

* An Important Bird Area (IBA) is a "discrete site that supports specific groups of birds: threatened birds, large groups of birds, and birds restricted by range or by habitat". [http://ibacanada.ca/iba_what.jsp?lang=en]

Figure 2.55. Thousands of Common Eiders spend the winter just offshore from the nominated property.

Figure 2.56. Over 4,000 pairs of Black-legged Kittiwakes nest on Mistaken Point's rock cliffs.

Figure 2.57. Capelin spawning (rolling) on a sandy beach in Portugal Cove South (August 2009).

Several seabird colonies, for example at The Rookery and Freshwater Cove, are located in the nominated property. Numerically these colonies are dominated by Black-legged Kittiwakes—a July 2009 survey tallied 4,170 pairs (Figure 2.56). Other cliff-nesting seabird species that breed within the nominated property (in much smaller numbers) are, in order of decreasing abundance: Common Murre, Razorbill, Atlantic Puffin, Black Guillemot, Herring Gull, and Double-crested Cormorant.

In foggy conditions during August, tens of thousands of Sooty and Great shearwaters gather in pursuit of Capelin (Figure 2.57), one of the keystone forage fish species of the North Atlantic, which mass in huge shoals offshore from the nominated property, especially along the coast from The Drook north to Portugal Cove South.

The Mistaken Point barrens are visited in August and September by hundreds of southward-bound, Arctic-nesting shorebirds, chiefly American Golden-Plovers and Whimbrels, that fatten-up on crowberries in preparation for their arduous, non-stop migratory flight to northern South America.[86]

In all, more than 180 bird species have been sighted in the area of the nominated property and adjacent waters (see Appendix 6 for a species list in the *Mistaken Point Ecological Reserve Management Plan*).

Mammals

The terrestrial mammal species encountered on the barrens and coastline include: Moose, Red Fox, Mink, River Otter, Snowshoe Hare, Short-tailed Weasel, and Woodland Caribou. Marine mammals include Harbour and Atlantic Grey seals, which are both regularly observed just offshore from the nominated property. Cetacean species, most commonly seen in summer, include Humpback and Minke whales and Harbour Porpoises.

Insects

Insects in the nominated property have been little studied but two species are difficult to ignore: blackflies and the beautiful Short-tailed Swallowtail Butterfly (Figure 2.58).

Fish

Brook Trout populations in the ponds inland of the nominated property and the streams that run through it have been reproductively isolated for 10,000 years, since deglaciation. Studies have focused on the genetics and ecology of Brook Trout populations and how the trout have adapted to the fragmentation of their habitat.

2.b History and Development

2.b (i) Geological history

Introduction

Earth is 4,560 million years old.[87] This immense span of geologic time is informally divided into the Precambrian (4,560 to 541 million years ago)—representing 88 percent of our planet's history—and Phanerozoic

Figure 2.58. Short-tailed Swallowtail – this striking butterfly is regularly encountered within and near the nominated property in summer.

(meaning abundant life) intervals (see Figure 3.4 in Section 3.2). During the Cambrian Period (541 to 485 million years ago), which marks the beginning of the Phanerozoic eon, remains of the ancestors of most modern animal groups first appear within the fossil record.

The youngest formal era of the Precambrian is the Neoproterozoic, whose ultimate time component (Figure 2.22) is the recently erected[88,89] Ediacaran Period (635 to 541 million years ago).[28] The middle Ediacaran rock succession contained within the nominated property spans the time interval from 580 to 560 million years ago (Figure 2.7).

Newfoundland and Avalonia

The island of Newfoundland lies at the northeastern extremity of the 3,000-kilometre-long Appalachian mountain chain.[90] This chain represents the eroded remnants of a previously high-elevation mountain range formed by the closure of the ancient Iapetus Ocean. The portion of the Appalachians in Newfoundland is divided into four main tectono-stratigraphic zones or terranes,*[19-22] the easternmost of which, the Avalon Zone,[14] includes the nominated property (Figure 2.15). Named for the Avalon Peninsula, the Avalon Zone is the type area for a composite, exotic superterrane that formed part of a discrete microcontinent known as Avalonia.[92-94]

The opening of the much younger Atlantic Ocean split this continuous microcontinent into West and East Avalonia.[15] Rocks of West Avalonia are found along the east coast of North America in New England, New Brunswick, Nova Scotia and eastern Newfoundland. On the other side of the Atlantic, the rocks of East Avalonia are found in England, Wales, southern Ireland, Belgium, southern Denmark, the Netherlands, and northwest Germany (Figure 2.59).[93,94]

Avalonia's Journey Through Time

The igneous rocks that form Avalonia's foundations record three main stages of arc-related magmatism reflecting this microcontinent's prolonged subduction history between 740 and 570 million years ago.[15] Approximately 650 million years ago, Avalonia accreted to the northern margin of Gondwana (the cores of what we now know as Africa and South America;[95] Figure 2.60) followed by the main phase of Avalonian arc-related volcanism (635 to 570 million years ago). The volcanic ash beds found within the nominated property, which play such a prominent role in preserving the fossils that constitute its proposed Outstanding Universal Value, were generated during this critical period.

Situated between 65 and 62 degrees south, when it separated from Gondwana in the Early Ordovician (about 480 million years ago), Avalonia began its long drift northward[96] to dock with the core of present-day North America and Greenland during the Devonian Period. The resulting closure of the Iapetus Ocean triggered the Acadian Orogeny[96,97]—the dominant mountain-building event in the formation of the Canadian Appalachians.[90]

Offshore, the Avalon Zone underlies Newfoundland's Grand Banks, attaining its greatest width of 750 kilometres at the Flemish Cap.[98] Some 30,000 square kilometres of the continental shelf east of the Avalon Peninsula is underlain by an 8,000-metre-thick succession of sedimentary rocks from the Cambrian to Devonian Periods, and possibly younger.[99] On land, however, nowhere on the Avalon Peninsula are there any rocks representing the last 400 million years of geological history prior to the most recent ice age.

It appears that, for the past 350 million years, the Avalon Peninsula formed part of an area of net erosion. Remains of a series of extensive peneplains found across Newfoundland are a landform legacy of these prolonged periods of stability and denudation.

* Terranes are (typically) far-travelled, fault-bounded blocks with different geological histories from adjacent blocks.[91]

Figure 2.59. Map showing a reconstruction of the Avalonia microcontinent prior to the opening of the North Atlantic Ocean (after Nance et al., 2002, figure 1; and Pollock et al., 2009, figure 1).

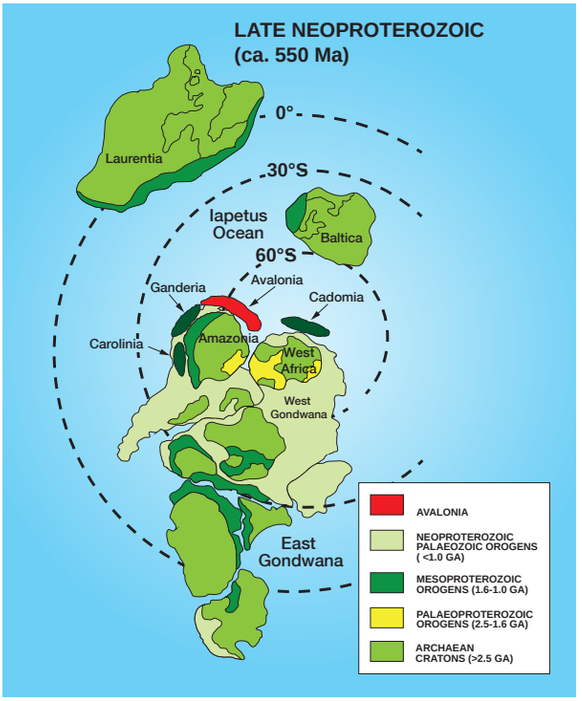


Figure 2.60. Palaeogeographical reconstruction showing the position of Avalonia some 550 million years ago during the late Ediacaran Period (modified from Pollock et al., 2009, figure 8).

Pangaea and the Formation of the Atlantic Ocean

By 310 million years ago, Laurentia–Avalonia was part of the supercontinent Pangaea. Newfoundland and the rest of Atlantic Canada lay near the centre of this gigantic landmass, which reached its maximum extent around 250 million years ago.[22,100,101] Initiation of the rifting that ultimately led to the break-up of Pangaea took place in the Late Triassic from 230 to 200 million years ago,[102] as North America drifted away from Europe–northern Africa.

In what is now eastern Canada, rifting and spreading began off Nova Scotia in the early Jurassic (about 200 million years ago) and continued north during the Early Cretaceous (118 to 110 million years ago) to the Grand Banks, and to northeast Newfoundland by the Late Cretaceous (80 million years ago). Rifting reached what is now the Labrador Sea by 53 million years ago.[22,103] By 25 million years ago, the North American Atlantic coast would have been recognizable.[104]

Stretching of the Avalon Zone crust off eastern Newfoundland during the Atlantic Ocean's development resulted in the formation of a series of deep, fault-bounded rift basins that now underlie Newfoundland's continental shelves. Some of these basins—such as the Jeanne d'Arc Basin, which hosts the giant Hibernia oilfield—are of major economic importance. Atlantic Canada's continental shelf typically extends for 200 kilometres offshore, but east of Newfoundland the shelf is 400 to 700 kilometres wide[22]—one of the largest in the world.[105]

The opening of the Atlantic Ocean and subsequent redistribution of continents around its margins had a major impact on the global circulation patterns of both deep and surface ocean waters. It is believed that the Gulf Stream had begun to flow at least 100 million years ago, but that the cold Labrador Current only became fully established approximately 4 million years ago.[103]

The Last Three Million Years

Canada's geological history over the last 3 million years has been dominated by the ice ages of the Pleistocene Epoch. During the Pleistocene, glacial ice reached sea level in eastern Canada as early as 2.75 million years ago. By 110,000 years ago, the Laurentide Ice Sheet had begun growing in the highlands of Labrador and Québec.[104]

In most parts of Canada, this vast ice sheet attained its greatest thickness and areal extent around 20,000 years ago—an event termed the Wisconsinan glaciation—but in Newfoundland, this last major ice advance occurred later, between 15,000 and 13,000 years ago.[105,106] Across the southern Avalon Peninsula the overall ice-flow direction was roughly northwest to southeast.[107] Final deglaciation of the Avalon Peninsula began about 10,500 to 10,000 years ago.[108] Around 6,000 years ago, the geography of Atlantic Canada was very similar to its modern version.[109] Since deglaciation, the nature of the eastern Avalon Peninsula's coastline has been, and continues to be, one of gradual sea-level rise and submergence.

Directly or indirectly, the landscape of the Avalon Peninsula (including in the nominated property) owes much of its present character to glacial erosion, deposition, and sea-level changes related to the Wisconsinan glaciation and subsequent deglaciation. It is uncertain when the nominated property's coastline assumed its present configuration. Similarly, the length of time for which Mistaken Point's main fossil-bearing surfaces have been exposed at their current areal extent is also unknown, but is suspected to be less than 500 years.

2.b (ii) Human History

There is no evidence of Aboriginal habitation in the area of the nominated property. The first people to see the coastline of Mistaken Point most likely were European explorers and fishermen. Though there is no documented proof, historians speculate that Portuguese explorer Gaspar Corte-Real may have rounded Cape Race in his caravel on his 1501 voyage and erected a banner near today's community of Portugal Cove

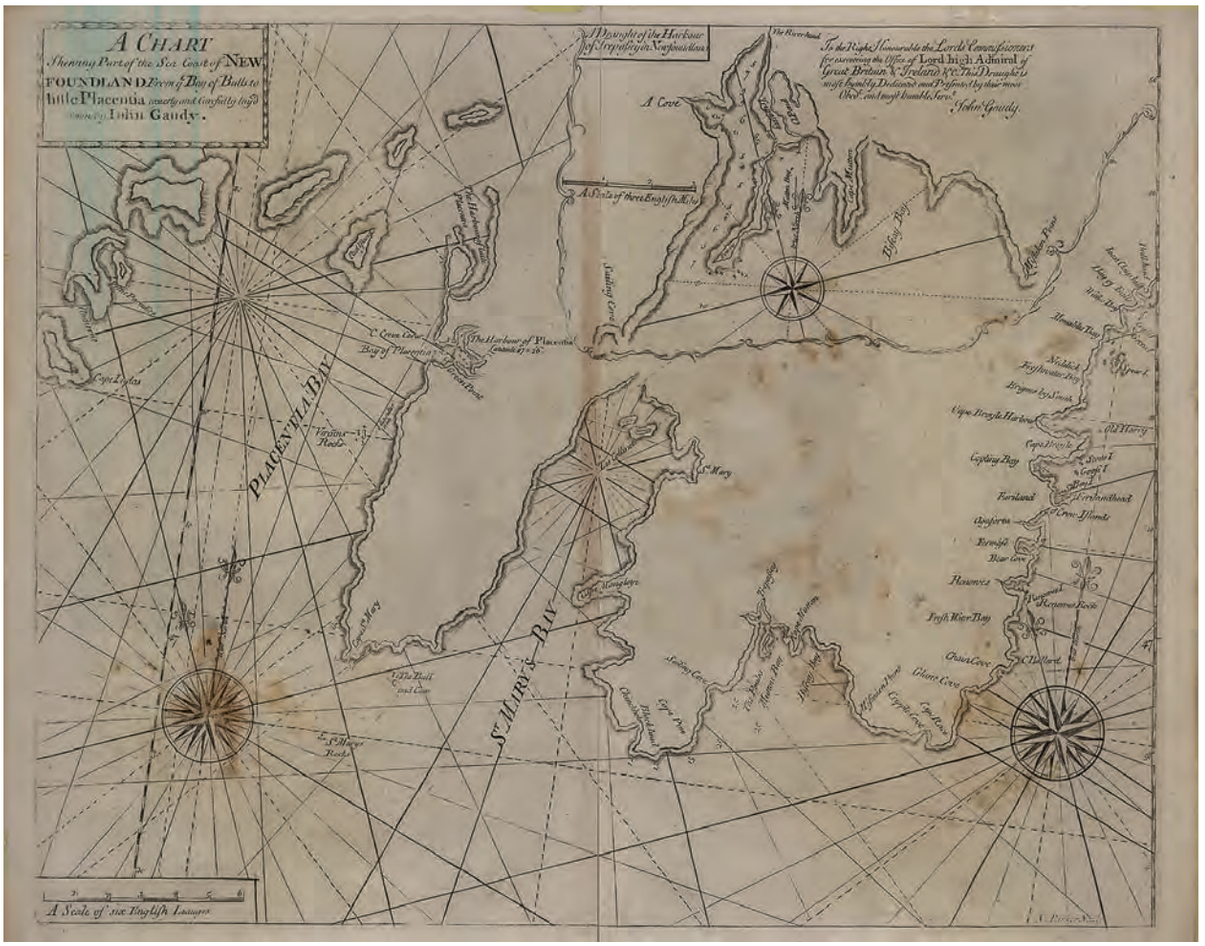


Figure 2.61. Map of the southern Avalon Peninsula by John Gaudy, published in 1715, showing the location of Mistaken Point (lower right).

Figure 2.62. Photograph (looking north) taken in 1945 of the former settlement in The Drook (The Rooms Provincial Archives Division, VA 15B-15.9 / L. Wulff).

South[110]. Certainly, however, Cape Race (which takes its name from the Portuguese *Cabo Raso*, which translates as flat cape) first appeared on a map in 1602.* By the 1600s, vessels from France, England, Portugal, and the Basque region in Spain were regularly sailing to bays near Cape Race to fish for cod each summer. Trepassey, to the west of Portugal Cove South and the first community to be established in the area, was settled by 1622. The earliest maps that identify Mistaken Point itself are those of John Gaudy published in 1715 (Figure 2.61) and Captain Cook (1770), who mapped this area as a prelude to his great voyages of discovery.

In the 1840s, about 50 years after Irish settler William Hartery became Portugal Cove South's first settler, fishing families began to put down roots close to the nominated property. They chose this difficult stretch of coast when demand for space in the less exposed, older settlements grew competitive following waves of 19th-century Irish immigration. People from Trepassey, to the west of the nominated property, and Renews, to the north, moved out along the rugged shoreline. Some locations in or near the nominated property were used seasonally (Bobs Cove, Bristy Cove, Watern Cove, Daleys Cove, Pigeon Cove), while others (The Drook, Long Beach) were settled more permanently (Figure 2.62).

The settlers' largely Irish–Anglo heritage is revealed in their family names—Coombs, Grace, Martin, Molloy, Power, Perry, O'Leary, O'Neil, Ward. Their use of the land and sea resources reflected general practice in many Newfoundland outports. Just offshore, they set nets and trawls daily during the fishing season. Along the rocky coast they built rock-cribbed wooden wharves, "stages" (covered wharf work areas) and stores, where they salted and dried their fish on wooden flakes, flat stones, or the cobble beaches. In private and communal meadows by the sea, they grazed sheep and cows (Figure 2.63). Near each of the widely scattered clapboard houses along the shore, settlers planted kitchen gardens and root crops. They supplemented their food supplies with hunting and gathering. Their activities revolved with the seasons: fishing, gathering berries, gardening, hunting caribou or seabirds, cutting wood for heat and boats, and mending nets.

None of the scattered settlements along the shore ever grew to more than a few dozen people, and all were eventually abandoned. By the early 1960s, the last of the residents moved to the larger community of Portugal Cove South and beyond. Little evidence of habitation remains to signal the presence of these

* The Barent Langenes "Terra Nova" map, was published in a small atlas in 1602 by Petrus Bertius.

Figure 2.63. Replacement of crowberry heath (dark) by grasses (yellow) as a result of past livestock grazing practices at Watern Cove.

hardworking people. The houses, wharves, and schools are gone. Descendants still have ties to their family land—a few seasonal cabins are in use today and local people continue to come to the area for traditional hunting and berry picking. Today, the Southern Avalon Peninsula generally—and the Portugal Cove South area in particular—is sparsely populated, owing in large part to the closure of the commercial cod fishery in 1992. Since then, the population of the region has declined dramatically and continues to do so (Figure 2.64).

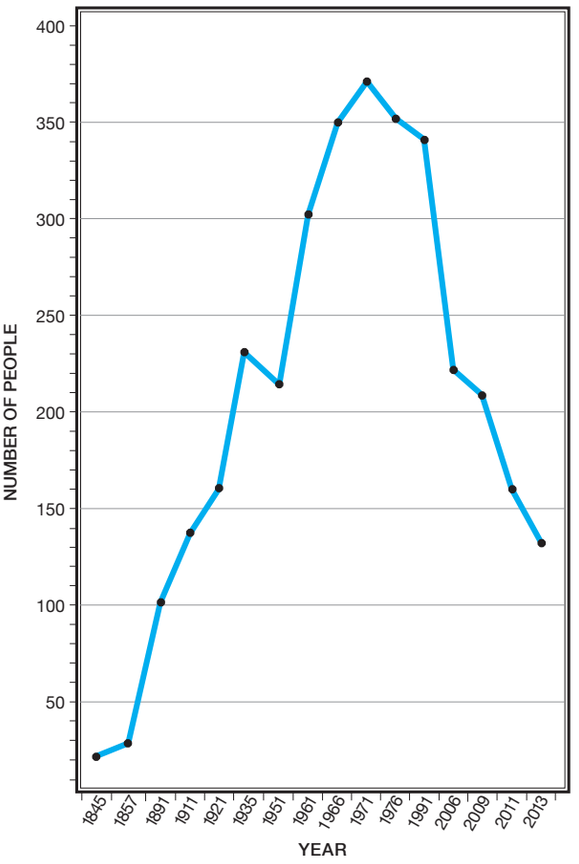


Figure 2.64. Graph showing the population history of Portugal Cove South from 1845 to 2013.

Figure 2.65. The historic lighthouse at Cape Race.

A single unpaved coastal road runs from Portugal Cove South to the Cape Race lighthouse (Figure 2.65). First lit in 1856, the lighthouse is an impressive aid to navigation. It was built, in part, to help ships avoid the error of changing course at the justly named Mistaken Point. Despite the presence of the lighthouse, the hazardous waters in the region have seen many shipwrecks, including the 1877 *George Washington* disaster near Bristy Cove and the 1909 total loss of the steamer *Laurentian* at Mistaken Point.

The fossil beds in the nominated property were known to local hunters and residents in the 20th century, although their significance was not understood. Oral accounts tell of children playing on the exposed beds and commenting on the "flowers in the rocks."

2.b (iii) History of Discovery and Scientific Investigation

The Discovery

One day in June 1967,[111] as Shiva Balak Misra (Figure 2.66) was following a short distance behind his field assistant Paul Thompson (Figure 2.67) on the coast just northwest of Mistaken Point, Thompson suddenly halted and called excitedly. Both men were there to map the Precambrian rocks along Newfoundland's southeast coast between Cape Race and Biscay Bay as part of Misra's master's thesis for Memorial University of Newfoundland (St. John's). What they discovered that day would totally change the world's understanding of the early evolution of life on Earth. According to a contemporary newspaper account,[112] Thompson glanced down at the rock he was standing on and noticed numerous impressions that appeared to be fossils. Thompson immediately called Misra, who, after examining the specimens, realized their enormous potential significance.

The first official, academic account of the Mistaken Point fossils appeared as a two-page note (Appendix 4) by Professor Michael Anderson (Figure 2.68) and Misra, in the 16 November 1968 issue of the scientific journal *Nature*.[113] They described the Mistaken Point fauna as a high-abundance, low-diversity assemblage of soft-bodied metazoans. They also noted that fossils had been "observed at five horizons" in a "small thickness of Conception beds" [*sic*] at Mistaken Point and that work on the specimens "has to be done in situ or using casts and peels."

The Mistaken Point discovery represented the first record of Ediacara-type fauna from the Western Hemisphere. Scientists were skeptical. Despite evidence to the contrary from, for example, Charnwood Forest in England,[33] conventional wisdom held that Precambrian rocks did not contain complex fossils. Typical of the general response was the September 1969 note by well-known British geologist Roland Goldring,[114] who suggested that the Mistaken Point "structures" were inorganic in origin and noted the "striking resemblances" of the examples illustrated to cone-in-cone structure (a distinctive growth-form of the mineral calcite).

Figure 2.66. Professor Shiva Balak Misra.

Figure 2.67. Paul Thompson.

Figure 2.68. Professor Michael Anderson (1923-2010).

Anderson and Misra's[115] rebuttal of Goldring's conclusions, plus Misra's[116] seven-page paper containing an additional eight photographic plates showing the main fossil types, which was published two months later, vanquished any lingering suspicions regarding the Mistaken Point fossils' authenticity. Instead of presenting formal diagnoses and scientific names for the fossils, Misra ascribed them to one of four categories of form taxa: leaf-shaped, round lobate, dendrite-like, or spindle-shaped.

More than 30 years would pass before the basic but essential palaeontological work of systematically describing and naming the various fossil types of the Mistaken Point assemblage would finally begin in earnest.

The 1970s

In a 1971 paper, published after his return to India, Misra[2] addressed the "stratigraphy and depositional history" of the rock succession at Mistaken Point. He mapped four formations along the coast, including what is now the nominated property, from oldest to youngest: the Drook, Freshwater Point, Cape Cove, and St. John's formations. Of these, the first three were newly erected by Misra with the type sections of both the Drook and Freshwater Point formations being located inside the nominated property. He concluded that the bulk of the rock sequence in what is now the nominated property was deposited by turbidity currents (see Section 2.a (ii)) in a moderately deep marine environment.

Michael Anderson continued the study of Mistaken Point's fossil assemblages. His work included the search for additional fossil-bearing units. He became Mistaken Point's foremost guardian and led the successful drive to secure formal legal protection for these invaluable fossils.

Following the publication of Anderson's and Misra's 1968 paper in *Nature* [113], numerous eminent geoscientists from around the world visited Mistaken Point. Among them were Hans Hofmann (then Canada's foremost expert on Precambrian fossils), Trevor Ford, who first described the genera *Charnia* and *Charniodiscus* from Charnwood Forest[33], and Russian palaeontologist Mikhail Fedonkin, who would later become the lead author of *The Rise of Animals.*[29]

During the 1970s and early 1980s, several teams of researchers visited the nominated property to obtain rock cores for palaeomagnetic analysis, in order to determine the palaeolatitude of its sedimentary sequence at the time of its deposition. To date, however, no palaeomagnetic results specific to Mistaken Point have been published. Research is ongoing.

In 1979, the publication of the Geological Survey of Canada's memoir and map of the Trepassey area marked an important milestone in our understanding of the geology of the nominated property. The memoir was written by Newfoundland and Labrador geologists Hank Williams and Arthur King. It introduced a revised stratigraphic subdivision of the region's Precambrian rock succession that has become the accepted framework used in all subsequent studies[9] and substantially modified Misra's localized stratigraphic scheme so that, of his formation names, only the Drook was retained.

The 1980s

Early in the 1980s, Anderson collaborated with renowned University of Cambridge palaeontologist Simon Conway Morris in a review of the Mistaken Point fauna. In their description of four unusual forms—spindles, bushes, pectinates,[117] and fractal fronds—they perpetuated the use of Misra's informal shape taxonomy.[116] Conway Morris would later write: "Amongst the Ediacaran localities there can be few more remarkable sites than Mistaken Point …."[118]

Meanwhile, in 1981, Misra published his interpretation of the depositional environments represented by the fossil-bearing rocks of the Mistaken Point area.[119] Regarding the life history, death, and preservation of the fossil assemblages, he drew significant conclusions:

1. The animals are preserved in situ.
2. They lived in a moderately deep marine environment.
3. In most cases, the fossil-bearing layers are covered by a thin volcanic ash layer suggesting that volcanism was responsible, at least in part, for the death of the organisms.
4. They probably lived on the ocean bottom during the quiet period between successive turbidity currents.

These frame the essence of the environmental scenario supported to this day by most students of the Mistaken Point biota—the world's first Ediacara-type fauna described from deposits generally accepted to be of deep marine origin.

When Mistaken Point Ecological Reserve was established in 1987 by the Government of Newfoundland and Labrador, fossil collecting there became illegal. Palaeontologists subsequently focused on the in situ examination of specimens and on making rubber moulds or plaster casts of them for laboratory study.

It was at this time that another researcher entered the picture and introduced precise dating of the nominated property sediments. A master's student

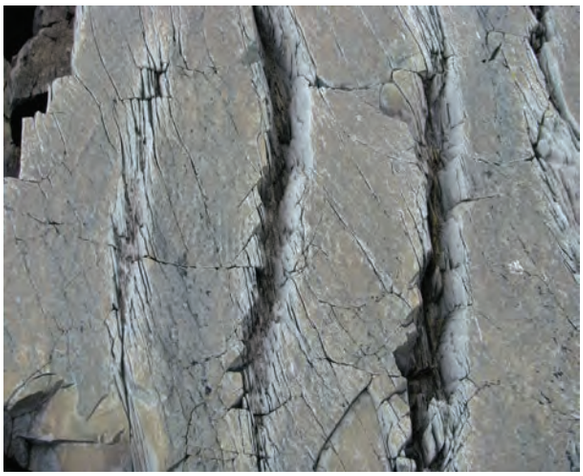


Figure 2.69. Close-up view of cleavage planes intersecting the D Surface. Shortening related to cleavage development has altered the fossils' original shape.

at Memorial University of Newfoundland's Department of Earth Sciences, Alison Benus, was completing her thesis project on the sedimentary rocks and structures of the upper portion of the Mistaken Point Formation at Mistaken Point and St. Shott's. Her results were published (in 1988) as an abstract[3] in the proceedings of the Precambrian–Cambrian Boundary Working Group meeting held in St. John's in August 1987,[120] and as part of the related field-trip guidebook.[12]

Benus' work is significant for several reasons. First, she used knowledge of modern sedimentary processes to interpret the site's geologic history through observations of sedimentary rocks and sedimentary structures. This enabled her to provide the first detailed sedimentological investigation of the rock sequence within the nominated property. Second, her publication of the high-precision, U-Pb radiometric dating obtained by Greg Dunning, then at the Royal Ontario Museum, provided the first such results for any Ediacaran fossil-bearing site. The findings challenged

Figure 2.70. Participants in the NASA Astrobiology Institute field trip examine the Pizza Disc Bed at Pigeon Cove (September 2009).

Figure 2.71. Professor Adolph ("Dolph") Seilacher (1925-2014).

the commonly accepted Precambrian–Cambrian boundary of 570 million years ago. The U-Pb results set the date at 565 ± 3 million years ago—considerably younger than expected. The date was obtained from a 10-centimetre-thick ash bed in the Conception Group, overlying the famous E surface at Mistaken Point (Figure 2.21). Third, Benus reported a total of nine fossil-bearing horizons from a 57-metre-thick sequence of the upper Mistaken Point Formation at Mistaken Point. Fourth, in her 1988 abstract Benus included the first acknowledgement of the effect of the pervasive "fracture cleavage" (Figures 2.19 and 2.69) at the site on the fossils' original shapes (up to 50 percent

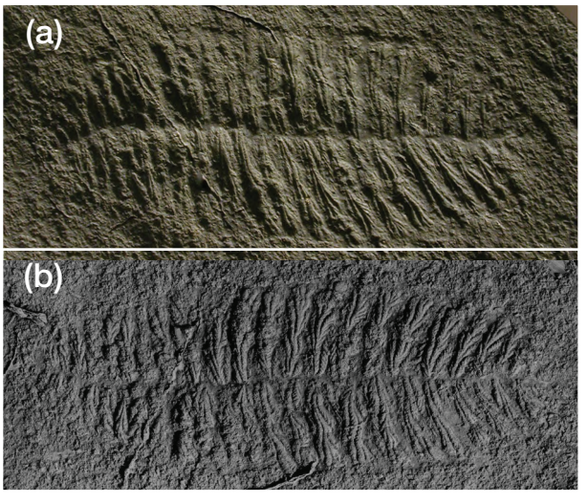


Figure 2.72. Specimen of *Fractofusus misrai*: (a) current, non-retrodeformed appearance; (b) original shape restored through retrodeformation.

shortening perpendicular to the plane of cleavage). Fifth, she not only confirmed and refined Misra's earlier interpretation (in 1971 and 1981) of these rocks as turbidity current deposits, but she also identified the influence of a bottom contour current. Finally, her schematic diagram labels showing fossil assemblages and lithological associations developed for the 1987 field trip to Mistaken Point[12] are the source of the names of significant Mistaken Point fossil-bearing surfaces including the D and E surfaces (Figure 2.2). Surface A in Benus' figure refers to the internationally recognized Pizza Disc Bed at Pigeon Cove (Figures 2.70 and 2.43).

In addition to the publication of Benus' research in the field trip guidebook research extracts, the 1987 field trip to Mistaken Point was significant for another reason. Two of the participants on the field trip, Dr. Guy Narbonne of Queen's University and Dr. Martin Brasier of Oxford University, would both later return to Mistaken Point and initiate major research programs.

The 1990s

During the summer of 1990, the renowned German palaeontologist Professor Adolph Seilacher (Figure 2.71) led a joint University of Tűbingen–Yale University expedition to Mistaken Point. Other researchers included sedimentologist Friedrich Pflűger, Yale student Rebecca Bendick, who made the first true palaeoecological analysis of the E surface[121], and Hans Luginsland, who created the first large-scale silicon casts of Mistaken Point fossils. These were illustrated by Seilacher in the 1997 book *Fossil Art*.[24] Seilacher and his co-researchers studied the Ediacaran fauna at Mistaken Point in detail. He placed this fauna in his newly erected Kingdom—the Vendobionta. In their fieldwork they concentrated on the main exposure of the E surface northwest of Mistaken Point itself (Figure 2.10). The E surface here is still referred to by some as "the Yale surface."

In an influential 1992 paper based on this work, Seilacher[76] described the structure of Ediacaran organisms and discussed their possible life histories, the environments they inhabited, and the events leading to their preservation. Regarding Mistaken Point, he concluded that each bedding plane represented an accurate fossil snapshot of the original deep marine community. In 1997, as mentioned above, he introduced the term "Ediacaran Pompeii" to illustrate the role of volcanic ashes or ash-rich turbidites in the fossilization of these benthic communities. He also described the need to eliminate the effects of tectonic strain on the fossils' shapes and orientations—a process for which Seilacher coined the term "retrodeformation"[24] (Figure 2.72).

The Queen's University Group

In 1998, Narbonne (Figure 2.73) of Queen's University, Ontario, began an ongoing long-term program of palaeontological and geological research at Mistaken Point. He has authored or co-authored many scientific articles on the Mistaken Point Ediacara-type fauna and their host rocks. He is also the lead author on seven field-trip guidebooks featuring the fossils and geology of the nominated property. These studies also formed the basis for post-doctoral research and graduate degrees by Dr. Jim Gehling (now at South Australian Museum, Adelaide; Figure 2.74), Marc Laflamme

Figure 2.73. Professor Guy Narbonne (right) showing Sir David Attenborough *Trepassia (Charnia) wardae* during filming for the television series "First Life" (September 2009).

Figure 2.74. Reconstructing fossil preservation on the E surface at Mistaken Point during a North American Paleontological Convention fieldtrip. The people in this photograph are from five different countries on four different continents, including Dr. Don Canfield (first from right), Dr. Jim Gehling (third from right), and Professor Guy Narbonne (fifth from right) (June 2005).

Figure 2.75. Dr. Marc Laflamme (third from right), Dr. Alex Liu (second from left), and Jack Matthews (second from right) during the GAC–MAC National Conference field excursion to Mistaken Point (June 2012).

(now a professor at University of Toronto, Mississauga; Figure 2.75), Matthew Clapham (now a professor at University of California, Santa Cruz), Donald Wood, Emily Bamforth, Lija Flude, and several undergraduate students. He has also worked closely with Australian fossil artist Peter Trusler.

Principal discoveries by the Queen's University group include the description and naming of the world's oldest large and complex fossil, *Trepassia* (*Charnia*) *wardae*[39] (Figure 2.33), a thorough stratigraphic and environmental interpretation of the Mistaken Point and Trepassey formations,[7] and naming and describing most of the taxa of the Mistaken Point assemblage (see Section 2.a(iii)). Work with Don Canfield (Figure 2.74) and Simon Poulton showed that the Mistaken Point fossils first appeared synchronously with a major rise in free-oxygen in the deep sea,[81] and work with scientists from the NASA Astrobiology Institute provided additional understanding as to how and why life increased in size dramatically 580 million years ago to produce the fossils of the Mistaken Point assemblage.[56]

Figure 2.76. Professor Martin Brasier (1947-2014).

Research undertaken by Matthew Clapham at the nominated property established an important milestone in the quantitative analysis of the palaeoecology of Ediacaran deep-marine benthic communities. Using data from three fossil-bearing surfaces, Clapham and Narbonne documented the development of a vertical stratified community structure above the sea floor in these fossil assemblages[65] (Figure 2.45). In 2003, Clapham and his colleagues measured and statistically analyzed the community structural attributes shown by census populations of organisms preserved on seven fossil-bearing bedding planes at Mistaken Point Ecological Reserve. Based on these data, they proposed a model of ecological succession[23] (Figure 2.46) within the Mistaken Point communities similar to that found today in animal communities inhabiting deep marine slopes. In 2011, Clapham employed his Mistaken Point data to illustrate the utility of mathematical techniques in the analysis of large palaeocommunity datasets.[122] Recently his palaeoecological data were reworked[78] in a size-frequency distribution analysis of five selected species on each of five fossil-bearing surfaces at Mistaken Point. The results were used to determine population structure and allow speculation regarding reproductive strategies of these ancestral animals.

The Memorial University of Newfoundland–University of Oxford Group

In 2007, Professor Martin Brasier, University of Oxford (Figure 2.76), and Professor Duncan McIlroy, Memorial University of Newfoundland, jointly initiated a broad-based program of palaeontological and sedimentological research into the Ediacaran succession of Newfoundland.

In 2009, as part of a paper demonstrating 3-D laser scanning as an aid in understanding evolutionary relationships within the Ediacaran biota in the nominated property, Brasier and Antcliffe described a new charniid rangeomorph, *Beothukis mistakensis* (new genus and species) from the E surface[31] (Figure 2.24). From a bedding plane approximately 50 metres stratigraphically above the E surface, Dr. Alex Liu (Figure 2.75) reported a series of trails (Figure 2.44) that he and his co-researchers believed represented the oldest unequivocal evidence for locomotion and, hence, animal-grade musculature, in the fossil record.[74,75]

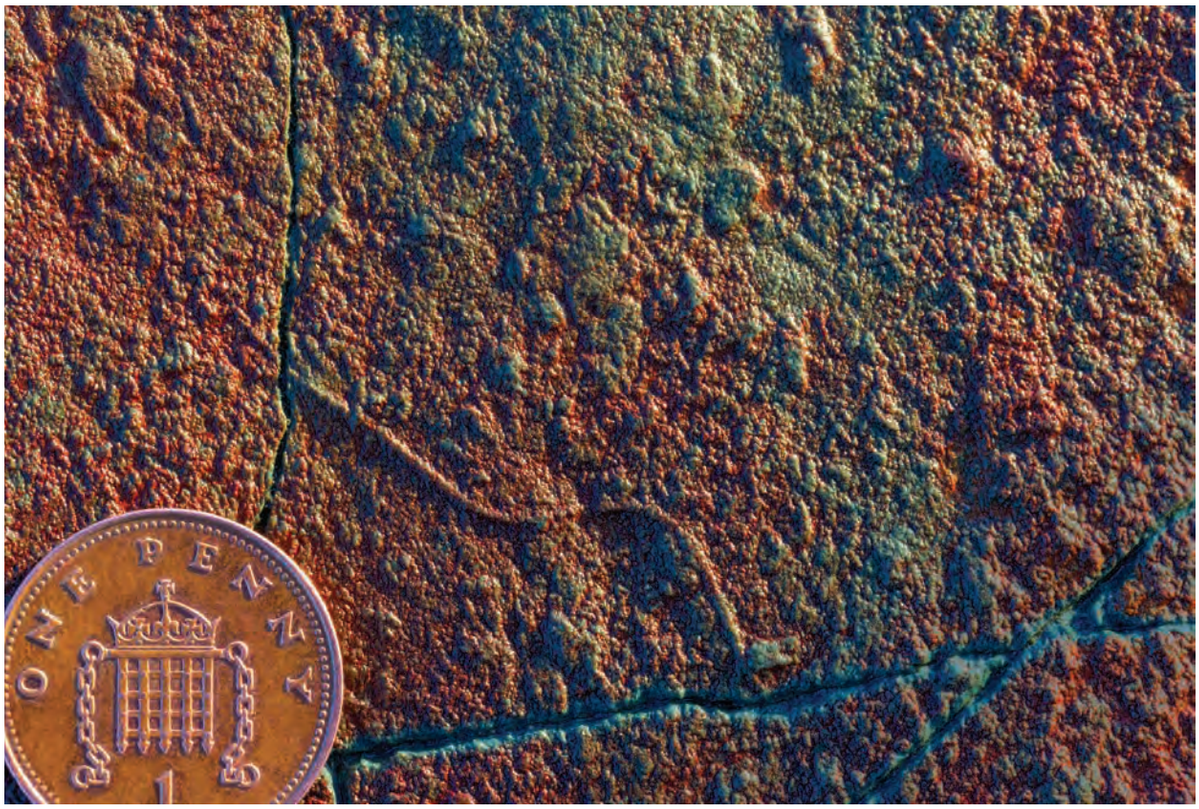


Figure 2.77. Fossil bacterial filament on the Pizza Disc Bed at Pigeon Cove. Diameter of coin is two centimetres.

In 2011, following an in-depth study of the familiar Pizza Disc Bed fossils of Mistaken Point (Figure 2.43), Liu and his co-authors[71] described the partially decayed remains of frondose organisms, which they termed "ivesheadiomorphs." In a subsequent paper,[80] they reported 129 juvenile frondose rangeomorphs of less than three centimetres in length (Figure 2.48) and numerous fossil filaments (Figure 2.77) from the Pizza Disc Bed at Pigeon Cove. The presence of these juvenile fronds on a previously colonized sea floor is interpreted as a "remarkable snapshot of secondary community succession."[80] The Pizza Disc Bed thus constitutes the earliest known example of such succession in the fossil record. A popular account of this discovery was published in the journal *Geology Today*.[123]

In 2012, the Memorial–Oxford group presented a new classification scheme for describing the architecture of frondose rangeomorph fossils.[43] In this article, Brasier and others amended the diagnoses of *Beothukis*, *Bradgatia*, *Hapsidophyllas, Fractofusus, Trepassia,* and *Charnia*, found at Mistaken Point Ecological Reserve, and erected a new genus *Vinlandia*. To this genus, they transferred the species *Charnia antecedens*.

Recently, University of Oxford Ph.D. student Jack Matthews (Figure 2.75) has been remapping the geology of the nominated property. He has also sampled a number of volcanic ash beds in the expectation of obtaining high-precision U-Pb radiometric dates from the zircon crystals they contain (Figure 2.20).

Other Research Work

Since 2000, other researchers have been advancing research related to the nominated property through fieldwork and sample analysis.

Figure 2.78. Dr. Phil Wilby preparing to mould fossils at Mistaken Point.

Figure 2.79. Sheridan Thompson.

Professor S.A. Bowring of the Massachusetts Institute of Technology, using U-Pb radiometry on zircons in the ash overlying the Pizza Disc Bed (Figure 2.8), obtained an extremely important date of 575 million years ago.[25] This was later refined by Bowring to 578.8 ± 0.5 million years ago.[26] This palaeocommunity thus represents the oldest, precisely dated, large, biologically complex fossils known anywhere in the world, and contributes to the proposed Outstanding Universal Value of Mistaken Point.

After a field trip to the nominated property in 2001, Dr. Kevin Peterson of Dartmouth College and his co-authors published a paper suggesting that some of the Ediacaran biota at Mistaken Point may have been fungus-like organisms.[124] Dr. Philip Wilby of the British Geological Survey (Figure 2.78) visited the nominated property in 2010 and found, in comparing animal fossils from the nominated property with those of Charnwood Forest, that 40 percent of the genera are unique to Mistaken Point.[67]

Also in 2010, Dr. Emily Mitchell, University of Cambridge, conducted a Real-Time Kinematic Global Positioning System survey to accurately map the locations of 4,360 fossils on the main D and E surfaces at Mistaken Point. Using advanced statistical techniques to analyze her spatial data, she concluded that most of the Mistaken Point organisms were osmotrophs (they absorbed dissolved organic carbon directly from the water column).

In 2014, master's student Sheridan Thompson (Figure 2.79) from Memorial University of Newfoundland's Department of Geography completed the first-ever analysis of coastal erosion within the nominated property.[84]

International scientific interest in Mistaken Point continues to grow and remains robust (see Section 3.2). At the time of writing, approximately 100 peer-reviewed scientific articles have been published that directly relate to the geology and palaeontology of the nominated property. The nominated property continues to offer Ediacaran researchers the opportunity to make major discoveries.

In recognition of the importance of protecting the nominated property's fossils, while at the same time continuing to advance research within the site, the Government of Newfoundland and Labrador's Department of Environment and Conservation partnered in 2009 with the Royal Ontario Museum for an ambitious project. With contributions from the University of Oxford, Queen's University, and the Johnson Geo Centre (St. John's), the partners contracted Research Casting International of Trenton, Ontario, to create a mould of the best-preserved 83.6 square metres of the main E surface at Mistaken Point (Figure 2.80).

2.b (iv) History of Protection and Community Stewardship

When the first scientific articles describing the remarkable fossil assemblages in the Mistaken Point area were published in late 1969, they aroused worldwide academic interest. Reports of the discovery and its importance in the popular media captured the imagination of the general public and stoked the interest of fossil collectors (Figure 2.81).

According to a newspaper story on 14 September 1969,[112] "To date only one of the fossils has been removed for study from the fossil bed." However, even at that early stage in its post-discovery history, Professor Michael Anderson, who was leading the investigation of the fossils, and Dr. Ward Neale, Geology Department head at Memorial University of Newfoundland, were expressing concern about the need to safeguard the site for future study and education.

News of Mistaken Point's ancient, extremely rare, scientifically invaluable, and beautifully preserved fossils inevitably attracted the attention of commercial fossil dealers. With no statutory protection of Newfoundland and Labrador's palaeontological heritage at that time, collectors' behaviour in what is now the nominated property depended solely upon their ethics.

As noted in the first popular account of the discovery,[125] as well as in an article published a decade later about collecting fossils in Newfoundland and Labrador, the highly indurated, siliceous, and brittle nature of the rocks at Mistaken Point meant that fossils could only be extracted intact "with the aid of a very

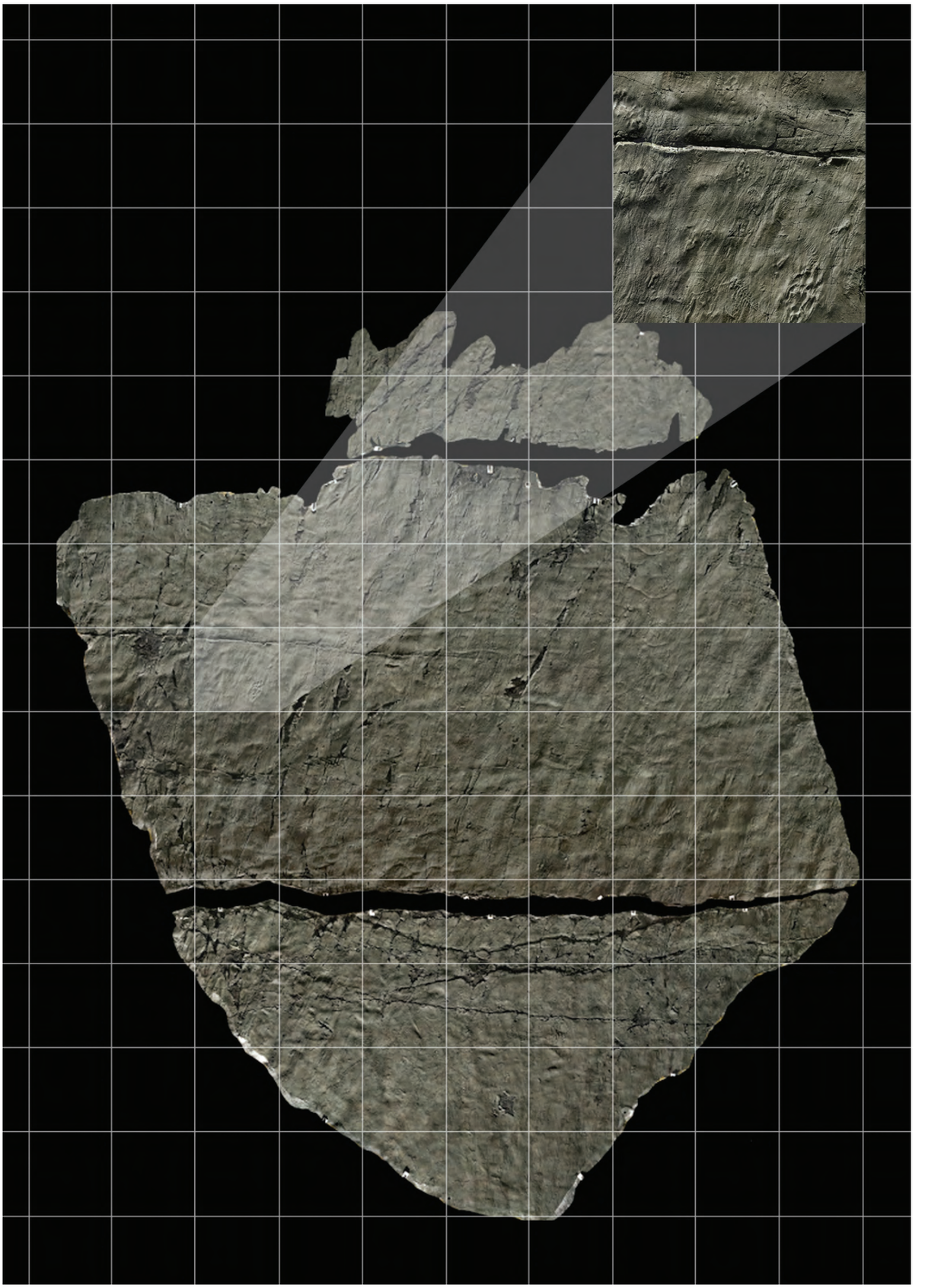


Figure 2.80. Digital photomosaic of the master cast of the main E surface at Mistaken Point, developed by Research Casting International. Metre grid for scale.

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Two MUN Students Accidently Made A Startling Discovery:

World-Wide Interest In M. U. N. Discovery

A routine study of rock formations resulted in a discovery of world-wide importance. Paul Thompson of Memorial accidentally discovered items which will cause scientists from around the world to visit Nfld.

When two University students set out for Mistaken Point, near Cape Race in 1967, little did they realize that they were on the threshold of an important discovery of world-wide importance.

What was meant to be a routine study of rock formation for S. R. Misra a post-graduate student at Memorial and Paul Thompson of St. John's an undergraduate assistant resulted in the find of some superbly preserved Precambrian trace fossils.

Discovery

To the layman this means that it is now possible to study some forms of life as it existed more than 600 million years ago.

Discovery of the Precambrian fossil bed with some of the earth's earliest known animals, many of them new to science, was made accidentally.

Paul Thompson, now with the Biology Department of Memorial University told the **Herald** that when he and Misra set out on the trip they were not looking for fossils.

One day Mr. Thomspon was standing on some rock when he happened to glance down and noticed what appeared to him to be fossils. He immediately called Mr. Misra who after examining the specimens became very excited over the find.

PAUL THOMPSON

New

The fossil discovery of this type is not only new to Newfoundland but to the world. Some fossils of the type found here have been found in southern parts of the globe, but they were of very poor quality and difficult to analyze.

The fossils found near Cape Race are very clear and according to the head of MUN's Geology Department Dr. Ward Neal scientists from all over the world will, no doubt, want to see them.

Dr. Ward told the **Herald** that generally traces of life are few and faint in rocks that pre-date those of the 500 to 600 million year old Cambrian Period although some are known in the Canadian Shield, and in Precambrian rocks of South Africa and Australia.

Imprints

The fossils are all imprints of soft bodied sea animals ranging from less than an inch to more than a foot in length. Skeletons, inside or outside, had not yet evolved when these remarkable creatures swarmed the Newfoundland seas over 600 million years ago.

They consist of six lobes and a central disc and look very much like the modern "moon jellyfish". Others are spindle shaped animals that achieved a length of nearly one foot and which bear some resemblance to the modern "sea pen". Other imprints resemble the leaves on mountain ash trees.

Best

Dr. Ward told the Herald that the Cape Race fossil bed contains some of the most varied and best preserved Precambrian life forms yet discovered.

So far, the find has been visited by Dr. Hans Hoffman of Universities de Montreal, Canada's ranking Precambrian expert.

Work on the find is being continued by Professors M. M. Anderson, and W. D. Brueckner of Memorial University sponsored by National Research Council grants.

S. B. Misra of India is currently in the Clarenville area but will study for his Ph.D at Carleton University, Ottawa, under Professor Alan Donaldson, an expert on Pre-cambrian sediments and ancient life forms.

Problem

One of the problems facing local Geology scientists is how to protect the find. Dr. Neale explained that the University is considering recommending to the Provincial Government that the area where the find is located be designated a National Monument.

If this is done, then it will be illegal for anyone to attempt to remove the fossils without approval by authorities.

Dr. Neale expressed the fear that if something of this an-

→Continued on Page 2)

S. B. Misra standing near the rocks at Cape Race which his studies and scientific publications will make world famous.

Figure 2.81. Copy of the first newspaper article to describe the discovery of fossils at Mistaken Point.

Figure 2.82. Hole left where a fossil was cut out of the main E surface near Mistaken Point, prior to the establishment of Mistaken Point Ecological Reserve.

expensive rock-saw"[126] (Figure 2.82). However, a number of private collectors used explosives and sledgehammers to obtain specimens from the edges of fossil-bearing surfaces at Mistaken Point.

Many of the fossils collected in the early years are now housed in Toronto at the Royal Ontario Museum (ROM), which has the largest collection of Mistaken Point fossils outside the nominated property. The ROM purchased many of the fossils removed by independent collectors during the 1970s and 1980s. When removal of fossils was still legal, ROM staff, using a diamond saw, also collected specimens under the supervision of Professor Michael Anderson.

Although separated from their palaeoecological context, archived collections of fossils from Mistaken Point, such as the one at the ROM, are a valuable resource for taxonomic studies of the nearly 20 fossil species recorded from the property.

The impact of the physical damage and loss of specimens from fossil collecting at Mistaken Point has been relatively minor, and the cumulative impact of such collecting on the site's overall integrity is negligible (see Section 3.1.c).

Against this backdrop of unregulated access and collecting, Anderson in particular, other academics, and some members of the Newfoundland and Labrador Geological Survey, lobbied for Mistaken Point to receive formal status as a protected area. Their efforts were successful on 31 July 1987. That is when an 8.5-kilometre-long strip of coast between Freshwater Point in the west and Shingle Head in the east was designated as Mistaken Point Ecological Reserve. As a result, the fossil-bearing surfaces were protected under Newfoundland and Labrador's *Wilderness and Ecological Reserves Act* (1980).

According to its founding legislation, the reasons for Mistaken Point Ecological Reserve's establishment are preservation of its unique fossils, encouragement of scientific research, and education— provided activities related to the latter do not conflict with fossil protection and scientific study. Provision for the continuation of traditional uses of the land base, such as hunting, fishing, and berry-picking by local residents is included in this legislation.

The provincial government agency designated with the legal responsibility for management of the original reserve was the Parks Division of the then Department of Culture, Recreation and Youth. Through internal provincial government changes, that authority now rests with the Parks and Natural Areas Division of the Department of Environment and Conservation.

Mistaken Point Ecological Reserve's strong legal protection prohibits the collection of fossils within the reserve except where important specimens are in immediate danger of destruction due to natural processes. While there were no local staff between 1987 and 2006, Mistaken Point's protected area designation, its relatively remote location, access via gravel road, and the vigilance of local residents (see below), as well as the commercial availability of specimens from other Ediacaran fossil sites, brought a halt to illegal removal of the fossils.

In July 1998, a grassroots committee—which eventually became Cape Race–Portugal Cove South Heritage Inc.—was formed in Portugal Cove South to promote and protect the area's natural and cultural heritage. Volunteer staff set up a temporary information centre. In co-operation with Parks and Natural Areas Division and researchers, members of that committee have demonstrated the commitment and interest of the local community in working to protect the fossils and their proposed Outstanding Universal Value, and to pass on their interest and sense of ownership and responsibility to younger generations.

Surrounded by diamond-saw cuts in the rock, a specimen of *Ivesheadia* (Figure 2.83) remains as testimony to the tenacity of Portugal Cove South residents in protecting the community's fossil resource. This particular specimen of *Ivesheadia* remains in place due to the action of volunteers who foiled illegal collectors in September 1998. In the book *Fossil Ecosystems of North America,*[127] describing access to Mistaken Point, the authors write: "The local people act as guardians of their fossil heritage and it is advisable to inform the Geological Survey in St. John's of potential visits in order to avoid confrontation."

Figure 2.83. In September 1998, the attempted removal of this *Ivesheadia* specimen by fossil collectors was foiled by local residents.

Catherine Ward (Figure 2.84), one of the original founders of Cape Race Heritage Inc., so inspired her son Bradley with her enthusiasm for the nominated property and its fossils that he began in his spare time to search for fossils—with spectacular results. In 1999, he discovered the large rangeomorph frond that has since been named *Trepassia* (*Charnia)wardae*[30,39] (Figure 2.33) in honour of the Ward family.

Figure 2.84. Catherine ("Kit") Ward – long-time defender and promoter of Mistaken Point's fossils.

This fossil was found outside the original boundaries of Mistaken Point Ecological Reserve, which meant it was not legally protected. Its discovery clearly demonstrated the need to expand the reserve especially since, if the location of this fossil became general knowledge, it would undoubtedly draw the attention of unscrupulous collectors. That was why, in October 2002 when Narbonne and Gehling alerted Parks and Natural Areas Division staff to the imminent publication of their paper on *Charnia wardi*,[39] immediate action was taken. The Newfoundland and Labrador Government—with input from its Wilderness and Ecological Reserves Advisory Council—moved quickly to declare an Emergency Extension to Mistaken Point Ecological Reserve on 24 January 2003. This prompt action provided immediate legal protection for these extremely significant new fossil sites. Narbonne* praised the establishment of this Emergency Extension as an exemplary model of co-operation among scientists, government, Parks and Natural Division staff, and local residents.

After being renewed in 2007, the 2.7-square-kilometre extension became a permanent part of Mistaken Point Ecological Reserve on 17 March 2009. The *Fossil Ecological Reserve Regulations* were also updated to include creation of a Fossil Protection Zone as an additional management tool for protecting the fossils within the entire reserve (see Section 5.c).

On 30 April 2004, the Government of Canada added Mistaken Point to its updated Tentative List of World Heritage Properties.[128] This in itself is a milestone accomplishment for any natural heritage site in Canada, given the rigorous scrutiny employed by Parks Canada, the federal agency charged with the responsibility for overseeing the production of high-quality nominations for inscription on the World Heritage List.

All new fossil discoveries unless already protected in an ecological reserve now come under immediate protection through the Province's *Palaeontological Resource Regulations* enacted in 2011 under the Newfoundland and Labrador *Historic Resources Act* (1985) (Appendix 2). These regulations specifically provide protection for significant Ediacaran fossils located outside existing provincial protected areas.

A key factor in the implementation of the protective policies and legislation related to the nominated property is the involvement of local volunteers. Since the discovery of the fossils in 1967, area residents have taken an increasingly active interest in their protection.

In April 2013, representatives of what was then known as the Mistaken Point (UNESCO) World Heritage Public Advisory Committee (established in March 2012) met in Portugal Cove South to map out the best approach for submitting a nomination of Mistaken Point for consideration for inscription on the World Heritage List. They concluded that what was needed was an incorporated community-based organization, with a broader scope and more focused vision that could acquire additional resources. Mistaken Point Ambassadors Inc. was incorporated shortly thereafter.

* G. Narbonne, personal communication, October 29, 2008

The Mistaken Point Ambassadors Inc. Mission Statement encapsulates the overall focus of its activities:

Mistaken Point Ambassadors Inc.'s mission is to pursue UNESCO World Heritage designation at Mistaken Point, acting as a co-leader, in partnership with the Parks and Natural Areas Division of the Department of Environment and Conservation, Government of Newfoundland and Labrador, to monitor the bid dossier development and submission process, to identify key planning, research and infrastructure requirements, to secure resources to ensure successful project completion and to facilitate stakeholder engagement.

Another key community-based volunteer group is the Mistaken Point Fossil Guardians (see Section 5.c). The Guardians work with Parks and Natural Areas Division to assist with protection of the nominated property at Mistaken Point.

2.b (v) National and International Recognition for Mistaken Point

In the nearly five decades since Misra's and Thompson's discovery of the fossils at Mistaken Point, news of the discovery and its significance has been communicated to millions of people worldwide through books, scientific journals, popular science magazines, newspapers (Figure 2.81), film, television and radio broadcasts, scientific field trips, and conferences. Mistaken Point has also featured in works of popular culture such as art, poetry, novels, and music.

Perhaps the most prestigious and definitely the most widely known of all the exposure comes from the Emmy-award-winning television series *First Life with David Attenborough* (Figure 2.73). Filmed by Atlantic Productions for the BBC–ABC–History Channel and first broadcast in 2010, the series received three Emmy Awards including Best Nature Programming. In this two-hour documentary, Mistaken Point is featured for 15 minutes in the first episode, "Arrival." In a written communication from Atlantic Productions spokesperson Denise Martin, their head of distribution estimates that as of October 2014, "First Life" has been broadcast to up to one billion people in more than 150 countries.

Some other productions that feature the nominated property include the Canadian Broadcasting Corporation (CBC) television program *The Nature of Things*. In the "Geologic Journey" series "Episode 5: The Atlantic Coast," broadcast on 7 October 2007 and narrated by David Suzuki, the focus of a significant part of the episode is Mistaken Point. The fossils of the nominated property were also discussed in Part 2 of the History Channel's television documentary series *Evolve*, which first aired 5 August 2008. The E Surface Casting Project (see Section 4.a (iii)) was featured in three episodes on the Discovery Channel's *Daily Planet Show* between October 2009 and March 2010.

CBC Radio, Canada's national broadcaster, has paid particular attention to Mistaken Point in various science, current events, and news programs, highlighting stories about research within the nominated property. These programs have featured the importance of scientific discoveries made at Mistaken Point and what the increasing level of understanding about these fossil assemblages reveals about early life.

The nominated property also garners mention in popular science books such as *Snowball Earth*,[129] *Darwin's Lost World*,[130] *Survivors*,[131] and *The Rise of Animals*,[29] and in magazines and newspapers such as *Downhome, Canadian Geographic, Reader's Digest,* and *The Toronto Star.*

Numerous formal geological field trips to Mistaken Point have significantly increased the international exposure of the nominated property and its fossils to scientists worldwide. Among the meetings that have attracted some of the world's foremost geologists and palaeontologists to this remote southeast corner of the Avalon Peninsula are: the International Union of Geological Sciences–International Commission on Stratigraphy, Cambrian Subcommission in 1987; the North American Paleontological Conference / International Union of Geological Sciences–International Commission on Stratigraphy, Neoproterozoic Subcommission in 2005 (Figure 2.74); the International Ichnological Association in 2012; and the Geological Association of Canada–Mineralogical Association of Canada National Conference in the same year (Figure 2.75).

One of the most interesting scientific trips occurred in August 2009, when the NASA Astrobiology Institute visited Mistaken Point (Figure 2.70) as part of their long-term mission to investigate the origins of biological complexity in the universe. Results of this NASA study at Mistaken Point were published in *Current Biology*.[56]

"A magnificent place and one that I feel hugely privileged to have seen" ***~ Sir David Attenborough, 2010***